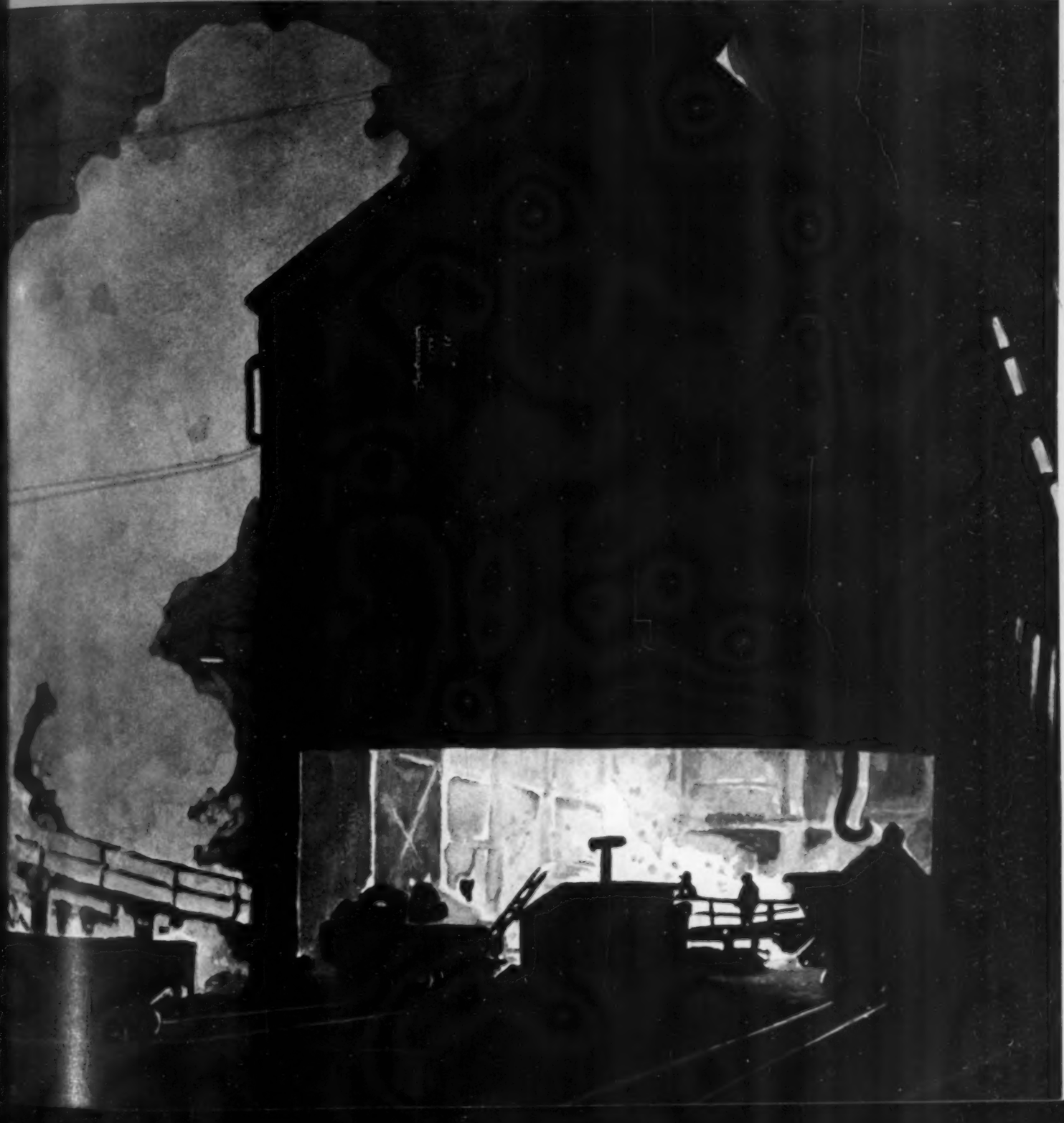
Mat Engin

METAL PROGRESS

NOVEMBER 1936

"STEEL PLANT," FROM A WATERCOLOR BY E. D. McDONALD



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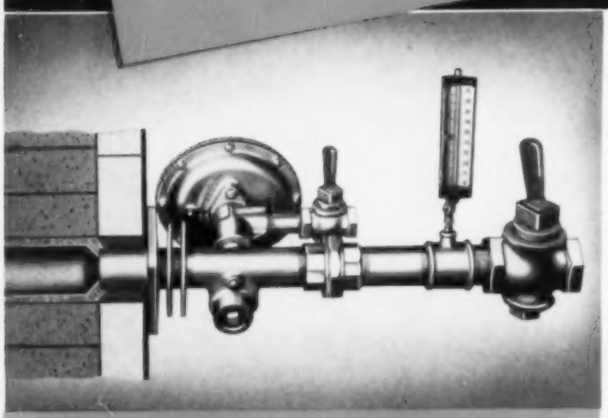
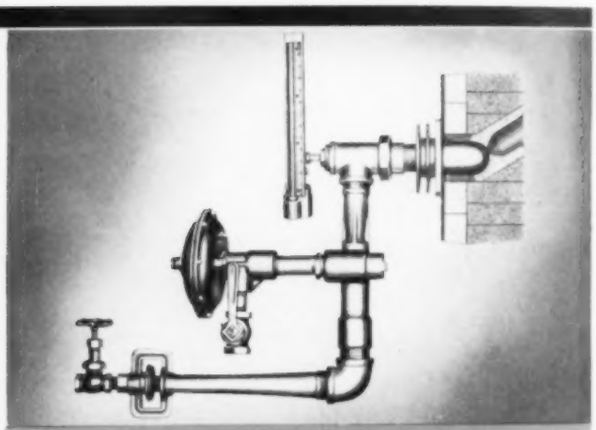


(ABOVE) SC LOW PRESSURE SINGLE STAGE VELOCITY BURNER SET
(BELOW) SC SINGLE STAGE HIGH PRESSURE VELOCITY BURNER SET
(UPPER RIGHT) SC LOW PRESSURE INSPIRATOR SET, MANIFOLDED TO SC TUNNEL



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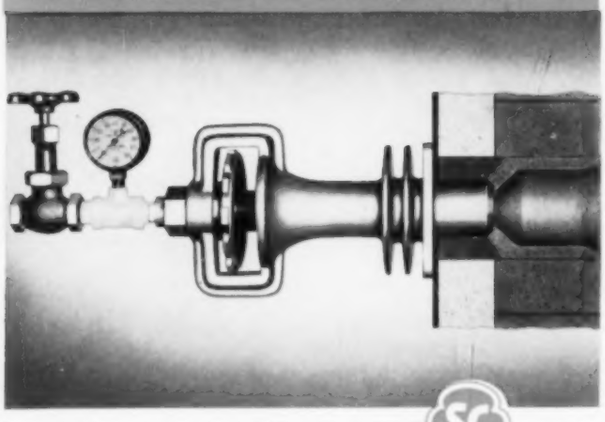

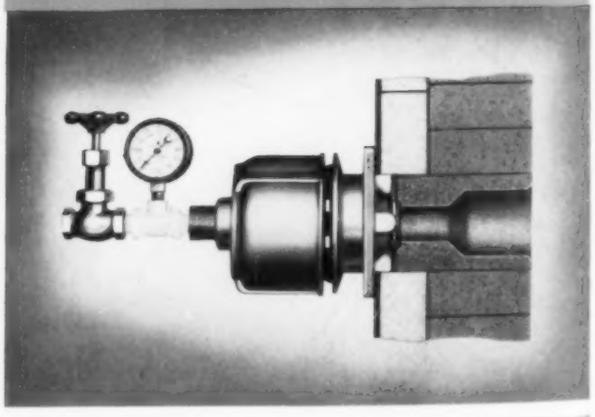

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METAL PROGRESS

NOVEMBER, 1936 VOLUME 30, NO. 5

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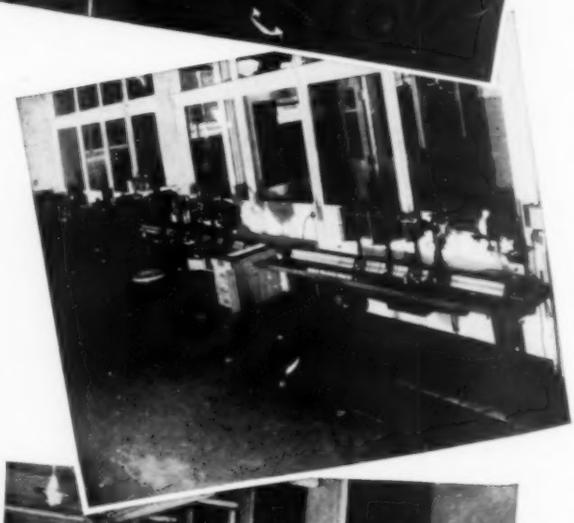
MODERN PROCEDURE IN ALLOY STEEL PRODUCTION

A Series of Advertisements Based on Timken Methods



No. 4

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METAL PROGRESS

VOL. 30 NOVEMBER, 1936 NO. 5

NOTES ON THE METALS CONVENTION

JOTTINGS BY THE EDITOR

THAT slightly dizzy feeling, the aftermath of a convention week as full as the Metal Congress, can no better be described than by American Society for Metals' Secretary W. H. Eisenman's words in opening his annual report:

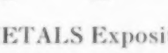
"After having presented 17 previous yearly reports, it is quite difficult to make this — the eighteenth — any different from the others. The items are the same — the figures vary. . . . It has been my privilege and pleasure to report progress in 17 of the 18 reports, so you may realize that the supply of descriptive adjectives may be exhausted. We have used such terms as excellent, splendid, admirable, outstanding, scintillating, stellar, arresting, and colossal, but not the 1936 term 'terrific.' Every year seems to set a new record — smashing the previous Olympic mark — and here we are again, with a new all-time high for membership and resources. With more papers for the congress than in any other year, and the largest exposition in history — Gentlemen, it's not only terrific, it's mastodonically terrific!"

As to statistics, the membership of the American Society for Metals is now above 8000 for the first time in history. Net gain in October (always a large month in number of accessions) was approximately 500 members; the nearest approach to that figure was 415 in October 1934. Operation of the Society has been quite successful financially, Treasurer Woodside's report showing that $30,000 was transferred to surplus, leaving the cash account practically the same as at the beginning of the year. Cash resources of the Chapters also increased $4000 to a grand total of about $56,000.

Registered attendance at the Exposition numbered 14,900 for the first four days, not counting many thousands on the last day, the only one when the doors were open to guests not bearing invitations. The exposition itself was the largest metal show in American history, exceeding past record-breakers by 13% in floor space, occupied by 217 exhibitors.

IN THE CAMPBELL Memorial Lecture, James P. Gill carried forward the tradition established by a long line of predecessors, who have presented each a serious study of some phase of metal progress. Whereas recent lecturers have generally discussed some phase of the newer alloys, or some scientific aspect of the modern methods of manufacturing, Mr. Gill devoted his attention to today's representative of the most ancient of all, namely tool steel. Thus the subject matter was one of lively interest, well presented. . . . One might think that standard high speed steel had been so intently studied long since that there would be but meager returns for further research. But the studies Mr. Gill has made endeavor to answer questions which any user has doubtless formulated in his own mind,

and the results will therefore be an immediate guide to practice. If indeed this lecture should be differentiated from its predecessors it would be that the information it contains can readily and immediately be utilized. . . . On pages 42 to 48 will be found only a brief outline of the whole, and it is a pity space is so limited, for as Mr. Gill said of one experiment, "It took a year and a half to perform, and a minute to give you the result!" It will, of course, be printed in full in a nearby issue of **Transactions.**



THAT THE METALS Exposition and Convention have acquired honorable status as an educational institution is demonstrated by the attendance of large numbers of college professors and undergraduates. Metallurgical departments at Case School of Applied Science and Carnegie Institute of Technology both adjourned for the week, and faculty, junior and senior metallurgists attended in a body. Cleveland was also made a point of call on three "senior trips," bodies of students traveling from such distant institutions as Stevens Institute of Technology (New Jersey), Colorado School of Mines and Missouri School of Mines. . . . That the two western mining schools should send students to the Metal Congress indicates that their historic preoccupation with the problems of ore concentration, reduction and refining is broadening out into serious consideration of the problems of the user and the fabricator of the common metals. This is as it should be, of course, for there are dozens of opportunities for graduates in manufacturing plants to one among the primary producers.

AMERICAN Welding Society's annual convention called for meetings mornings, afternoons and some evenings all the week long. A man whose prime interest is welding could find enough here to occupy his entire time; any other who wanted to sit in on other programs had to keep his eye on a time table and make some quick jumps from hotel to hotel, and hotel to Exposition. Fortunately most of the Welding Society's papers were preprinted in the October issue of its **Journal.** . . . President-Elect is A. E. Gibson, executive vice-president, Wellman Engineering Co. of Cleveland, whose interest is primarily in the construction of heavy machinery for severe service — like excavators, car dumpers, gas producers and chemical plant. In much of this enter the newly developed high strength, low alloy steels; besides the problems of welding extra heavy joints in medium carbon steel Mr. Gibson has wrestled with the special technique required for alloys. . . . E. R. Fish, chief engineer of the boiler division, Hartford Steam Boiler Inspection and Insurance Co., is the new senior vice-president. If memory serves, Mr. Fish's company was insuring welded pressure vessels (both fired and unfired) when made under procedure control, years before the American Society of Mechanical Engineers adopted the present code — in fact, this circumstance did much to encourage the cautious Boiler Code Committee to conclude that a welded vessel, properly made, inspected and tested, is just as reliable as a riveted one.

IT WAS a pleasant circumstance that Professor Sauveur (in whose honor the Albert Sauveur Achievement Award was established three years ago) could be present at the American Society for Metals' banquet, and present it to W. R. Chapin, the 1936 recipient. Zay Jeffries read the citation of merit (Dr. Jeffries being the only other holder of this honor). . . . Mr. Chapin's pioneering work, published in **Transactions** of the American Society for Steel Treating in 1922, determined the fact experimentally that austenite transforms into martensite not at temperatures a little below the critical, as was ordinarily supposed, but at 300° F. or less. Some cooling curves made earlier in France by Portevin and Garvin had indicated the presence of a delayed transformation in quenched carbon steel, but all three experimenters were several years ahead of their time. In America, at least, a reasonably clear exposition of the mechanism of quenching was not given until 1930, when H. J. French summarized several years of experimentation on quenching rates at the Bureau of Standards, and Davenport and Bain presented their studies on transformation at subcritical temperatures at the U. S. Steel Corp. Research Laboratory. . . . So little remembered, indeed, was Chapin's fundamental work that it is not even listed in the lengthy bibliography in Samuel Epstein's recent monograph on Constitution of the Alloys of Iron and Carbon.

THE PRESIDENT'S BELL, donated some years ago by Past-President Robert M. Bird, was awarded to the Peoria Chapter, which in President Archer's opinion had shown the greatest progress during his administration. G. C. Riegel, metallurgist of Caterpillar Tractor Co., was chairman during this period.

KUDOS of The Wire Association, in the form of a bronze plaque, was extended to Robert Notvest, chief engineer of the welding division, J. D. Adams Co., Indianapolis, for his paper "Steel for Arc Welding Electrodes," judged the best submitted to the Association during the past year. . . . The Association plans to enlarge its scope to include all non-ferrous wire drawing and (probably) cold drawn bars and shapes.

AS FOR the Metal Exposition — it defies description; to see it was to appreciate it. Fortunately the unrivaled facilities at the Cleveland Public Auditorium — high, banner-draped ceilings, wide aisles and commanding vistas — gave an impressive air of spaciousness to the entire show, and most of the exhibitors made the most of this feature. Open space, seemingly, is as necessary for a proper display as something to display. . . . Intelligent combinations of bright and shining metal and light-colored panels in backgrounds with harmonious rugs and luxurious furnishings proved that in only a few years we have outgrown the dark plush and wicker furniture era. . . . Nor was it all eye appeal. Reports from inquiring visitors have it that the booths were manned with engineers rather than ballyhoo artists. Detailed information of a technical nature was everywhere available. And from the other parties to a bargain — the exhibitors — came equally pleased comment as to the caliber of the men who approached them for news about their product. . . . Color, space and motion seemed to be the three main methods of attracting the eye. "Color" included bright and shining metal work — utilized, of course, by most metal producers. Motion was frequently the magnet drawing attention — welding processes demonstrated; cutting machines both flame and mechanical in operation; movies and talkies galore (including a robot who moved from photograph to photograph explaining the elements of alloy steel manufacture); hardening equipment in mass production, both heat treatment in controlled and circulating atmospheres and surface hardening by induction heating; complete plating installations for bright electrolytic coatings; a rotating globe with the continents mapped in brilliant carborundum — these are only some notable ones among many. Extensive operating exhibits were also installed by the companies manufacturing furnaces and furnace auxiliaries, pyrometers, recording and control devices, and optical and physical testing equipment.

HENRY M. HOBART received the 1936 award of the Samuel Wylie Miller Memorial Medal from the American Welding Society. Hobart and Miller were contemporaries, and both enthusiastic pioneers. Almost exactly 19 years ago, Hobart, a consulting electrical engineer for General Electric Co., was sent to England by the Emergency Fleet Corp. to study the welding methods of British shipbuilders. His report was undoubtedly the most comprehensive account of arc welding then available to Americans — who, at that time, were on the whole more interested in the older oxy-acetylene process than its youthful competitor. . . . Everyone knows what an important factor all the welding and cutting processes were to the army and navy during the War, but so many problems were solved by trial and error that a Welding Research Committee was speedily formed and its activities (thanks to the continued interest of Engineering Foundation and American Welding Society) continue to the present day. One most important branch of the work — on fundamental research — was then and still is under the direction of Mr. Hobart, and the number of projects has increased from a mere handful to more than 60.

SYMPOSIA (if one must use the word at all, he really should use that plural rather than the Americanized form symposiums) and "round table discussions" are now the style in program making. American Society for Metals indulged in a two-day consideration of the Plastic Working of Metals which will occupy at least one complete issue of **Transactions**; the Iron and Steel Division and the Institute of Metals Division, A.I.M.E., devoted one day to Physical Tests and Their Significance — some notes on which will be printed later — and the American Welding Society in conjunction with the American Society of Mechanical Engineers used two days (four sessions) in a Welding Practice Symposium. The latter may be regarded as an auxiliary phase of the work of a recently organized group of men, chairmanned by Col. G. F. Jenks of Watertown Arsenal, who are to accumulate and correlate the available information on the industrial aspects of welding all the common metals. . . . To those that take their *symposia* seriously, it was a matter of regret that the *chefs de programme* did not do some team work on the *agenda*. All this intellectual fare was served on Thursday and Friday, and is likely to be indigestible in such doses.

LAST YEAR and the year before a special effort was made to appeal to the less theoretical and more practical minded men with a series of lectures on some bread-and-butter phase of metallurgy. In view of the success of these past efforts, two lecture courses were arranged, one meeting late in the afternoon and one after supper. H. D. Churchill, associate professor of mechanics in Case School of Applied Science, gave five talks on Physical Testing and Interpretation of Test Results, while Kent R. Van Horn, research metallurgist, Aluminum Co. of America, presented three on X-Ray Analysis. Attendance was not only large, but held up well to the end. Undoubtedly this is a worth-while feature of the Metal Congress. . . . Professor Churchill's talks have been published in an attractive volume.

SEVEN colleges held luncheons, Wednesday noon, for old grads, friends, and undergraduates in Cleveland for the Show — pleasant affairs, all of them, and likely to be repeated in 1937.

"Curiouser and curiouser," cried Alice, for indeed her adventures in Alloyland were something to marvel at. Alloyland, you know, is a place that grows and changes from day to day, so that it is hard even for an inquisitive little girl like Alice to explore all of its wonders. But she is also a persistent little girl and every year she sets out to attend the National Metal Congress so she can learn the answers to a lot of those puzzling questions that popped into her head about Alloyland — where else can she get the answers so quickly?

ALICE IN ALLOYLAND

TEXT BY W. D. WILKINSON, JR.; DRAWINGS BY EARL J. NEFF

"IT'S TONS AND TONS every minute!" Alice heard a rough voice say.

"Who's there?" demanded Alice crossly, for she had a very bad headache. She had just figured out that all the money spent in replacing worn out machinery and rusty steel parts would easily support all the unemployed in the country. The thought of so much waste was so *very* depressing that she had an exceedingly bad headache indeed.

"Who's there?" she repeated impatiently.

"Alloy," was the response.

"Alloy who?" asked Alice.

"Allow me to present myself," returned the strange figure that now entered the room. Alice was amazed to see a pig bowing before her, and this pig appeared to be made entirely of iron.

"You should have said, 'knock, knock,'" reprimanded Alice; "and it isn't polite to run into my room without asking permission."

"I have to keep away from knocks, because I'm so brittle; and I couldn't help running from the furnace — it's so blasted hot there," apologized the pig, quite out of breath.

"Anyhow," said Alice angrily, "I think you ought to be more refined."

"You're telling me," said the pig sadly.

"Moreover," continued Alice, "you are a dirty little pig for not answering my question. Who are you?"

"Iron."

"Iron who?"

"I run up here to answer you," returned the pig ironically. "You were wondering about the amount of iron and steel that rusts, and I told you, 'tons and tons every minute.'"

"How did you know what I was thinking about?" demanded Alice.

"Every bright person ought to be thinking about that; besides, I'm a mine reader," explained the pig, referring to his subterranean ancestry.

"I think you mean mind reader —" began Alice; "but we won't stress the point," she added hastily, as the pig began to assume an unbending attitude.

"You're right," said the the pig approvingly, "never stress nothing that don't contain no alloy; it might break."

"There is much truth in what you say," reflected Alice. "You speak honestly even if unrefined. Personally, I prefer a crude person who

"Let's steal away to Steel," said the Pig . . . .

is honest, to a refined person who is dishonest."

"Say, kid, I'm for you," responded the pig, eyeing her Charpy. "Let's you and me steal away to Steel."

"It sounds dishonest," objected Alice.

"I don't mean to steal, I mean to 'Steel,' the capital of Alloyland."

"How do we get it — or there?" asked Alice confusedly. "I suppose, if it involves all that capital, it wouldn't be stealing, exactly, but — How do we get to Alloyland? Take a spring in the air and land there?"

"A good chrome-vanadium spring would do if we had one," said the pig, "but we had better take the Ferry. There's some pretty dangerous customers hanging around Alloyland; only the right Ferry will help protect us."

"Dangerous?" gasped Alice, feeling all shivery.

"Sh!" hissed the pig, "the Agents!"

"Communists?" asked Alice.

"Worse than that," moaned the pig.

"Nazis?"

"It's the Corrosive Agents," and the pig's face blanched until he appeared to be made of white cast iron.

Alice was overwhelmed. "I want to go by the safest Ferry afloat. Where is that?"

So the pig accompanied her to a large Ferry that looked very popular and guided her aboard. It seemed quite impervious to any attacks of the Agents. "This is the Ferry Chrome," he said as they left shore to the brave shouts of friends seeing them off.

On their journey to Alloyland the pig told Alice many interesting things about the country and its inhabitants and about the passengers on the boat. It appeared that in the city of Steel, one of the strongest and most rugged inhabitants, as well as the brightest and most polished, in fact the best all-round citizen, was an individual named Yum — Chromi Yum. Moreover, he was a warrior — a hard foe — as the Agents had to admit.

Likewise, Alloyland itself, like all prosperous countries, has had to solve the problem of immigration. According to one theory, a very large influx of even the most desirable elements requires special control if they are to be properly assimilated and welded into the social structure. The present tendency, however, as Alice gathered from the pig's quaint metaphor,

is to adopt the quota system, which eliminates the need for any special control of the immigrants, once they are admitted. The ratios of the various races — Ferrian, Non-Ferrian, etc. — are so balanced that they mutually accentuate their good qualities, and they always behave themselves. Under the old system, an immigrant was regulated and controlled, being suddenly plunged in oil or water and drawn this way and that until he would lose his temper. Under the newer system, well-disposed elements are usually provided with suitable companions and then left strictly alone.

Said the pig: "My old woman told me that when Chromi Yum last came into the country, he brought — ho, ho, can you bear it? — a nice, refining companion into it, to wit: N_2."

"What do you mean by 'into it to it into'?" asked Alice, who was not acquainted with legal or chemical terminology.

"I did not say, 'into it to it into'; I said, to wit: 'into it, to wit: N_2' and that's what she said, my old woman."

"Oh dear," said Alice, "no doubt she said all those N-two's, but what does she mean?"

"N-two means nitrogen — go to the foot of the class," commanded the pig.

Just then they were interrupted by the appearance on deck of a handsome stranger. Alice needed no introduction to know that she was in the presence of no other than Chromi Yum. "Oh, Mr. Yum!" was all that she could say, "I've heard that you're simply perfect. Is that true? Of course, I know it is."

Chromi Yum bowed in his highly polished way. "Call me Chrome," he said in a gallant, friendly manner, and then said modestly: "It is true that I have done my share, probably more than my share, for the benefit of my country. As a result, my fellow citizens importuned me to have a son to spread my name and fame. At first, I was hardened against the idea — heir-hardened, so to speak. People began saying that I was too hard to get along with. But I finally gave in, and now I have both a daughter and a son — Titani Yum and Columbi Yum. When I am with them, I am as soft and pliant as any loving father. They help me do many things that I could not do by myself, and nobody criticizes me any more."

Suddenly the watchful Chrome stepped to the port rail and shouted to a rapidly approaching craft which his keen eyes had espied in the distance. "Ship alloy!" he shouted, "are you the Agents? If you are, you can't come aboard." After a tensile moment, Chrome cried joyfully, "It's Nick and his Moll."

"Moll who?" asked Alice.

"Just call me Moly," answered the female arrival.

"Nick who?" pursued Alice.

"'Ell," responded Nick like a profane Cockney.

"You ought to know all about him already," sputtered the pig. "Him and Chrome and Moly are a tough combination to fight off the worst Agents."

"What about me?" interrupted a voice from the craft that had brought Nick Ell and Moly.

"It's that Rooshian," said Nick.

"A Russian, eh," said Chrome. "He may be a trouble maker. Ahoy, there, are you a Red Russ or a White Russ?"

"I'm a Phospho Russ," was the answer.

"Aha! I've heard of you. You're a trouble maker sent by the Agents. You were deported because you tried to disintegrate Alloyland, and now we're going to cast you out again."

"Cast me if you will, but not out! If I caused any trouble in Alloyland, it was because I was mistreated. Treat me right, and I'll help you fight the Agents. I —"

"Wait," said Chrome, "Does anybody here know Phospho Russ?"

An Oriental whom Alice later learned to know as Tung Sten approached and said quietly, "In my lowly capacity as principal element in Tool Steel" — Alice gathered that Tool Steel was a Chinese district in the capital of Alloyland — "I have noted that honorable Phospho Russ has been of notable assistance by lessening the resistance to my progress."

Although Moly had said something about not trusting a Chinese, a Japanese, or a Manganese, everybody knew that she hadn't meant what she said, and most people agreed that Phospho Russ should not be considered an undesirable alien. Even Moly was mollified.

"All right," agreed Chrome, likewise passivated,* "let him in, but watch him."

---

*A survey of early metallurgical literature indicates that the White Knight was the first to suggest using a boiling solution containing acetic acid for the passivation of steel. The White Knight is quoted as saying:

> "I heard him then, for I had just
> Completed my design
> To keep the Menai bridge from rust
> By boiling it in wine."

See Lewis Carroll, "Through the Looking Glass," Chapter VIII.

Phospho gave a sigh of relief at the verdict but was on the verge of collapse until a low caste seaman gave him a drink from a foundry flask. The seaman said, "I ain't no high-test casting wot's been to college, but I'm pretty handy even if I ain't passed no examination."

"How are you handy?" asked Alice.

"When I ain't casting off, I sings. Listen:

"The foundryman and patternman
Were talking close at hand,
'Just why our castings break so much
Is hard to understand!'
The former blamed the patterns
And the latter blamed the sand.

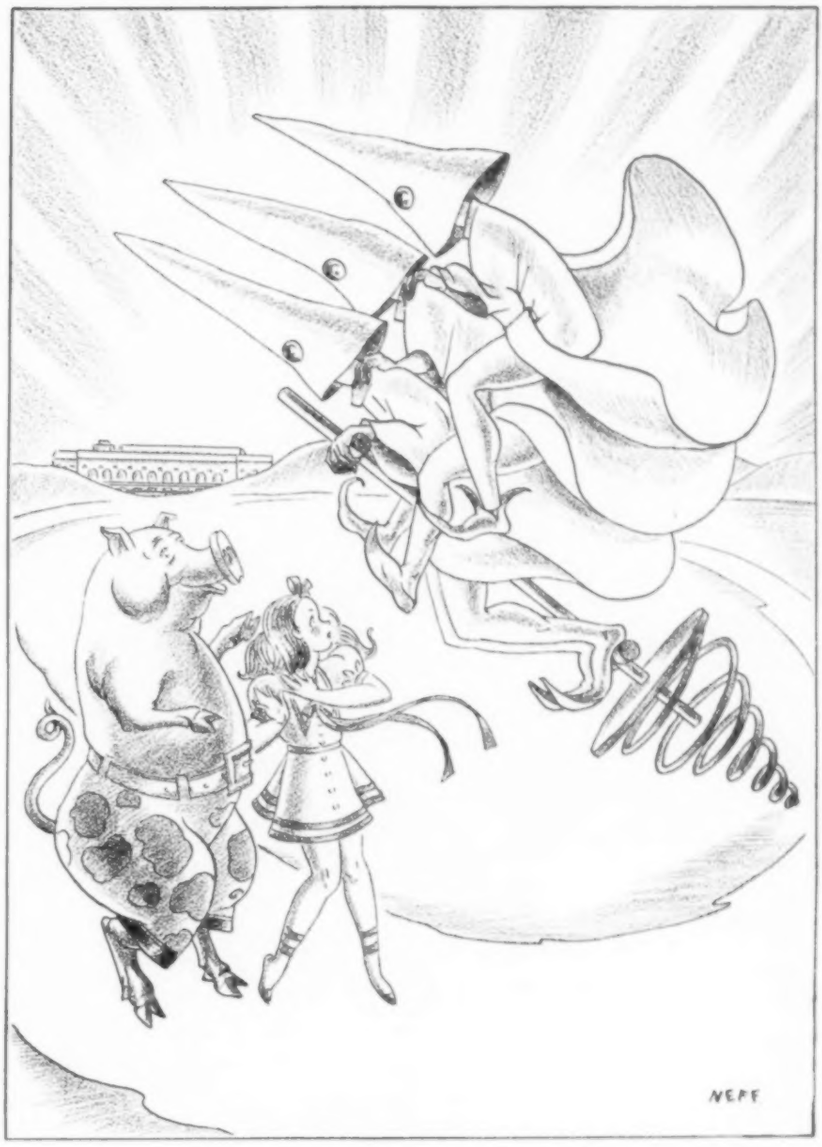
"Then four briquets did hurry up
And scarcely paused to greet:
'We'll make your castings strong and sound
And smooth and clean and neat —
Just put us in a cupola,
We're eager for the treat.'

"The foundryman and patternman
Talked on a while or so
And rested by a cupola
Whose runs were graded low;
But those briquetted alloys came
And waited in a row.

"And more briquets did follow them
And yet another four
And thick and fast they came at last
And more, and more, and more —
All hopping to the cupola
And scrambling in the door.

"'O Alloys,' said the foundryman,
'We've had a splendid run!
I surely hope you'll come again?'
But answer came there none —
And this was scarcely odd, because
They'd melted every one."

After this fine old chanty Alice noticed that the Ferry was arriving at its destination and that a welcoming throng had already gathered on shore. Principal among them was Alumin Um. "Hello, Al," said Chrome. The two were very friendly; Al's English ancestors were thought to belong to the celebrated Yum family, for research in heraldic literature had shown that they had sometimes spelled their name: Al You Mini Yum.



The Three Most Prominent Nightriders

Just then an astonishing figure came bounding along with prodigious leaps on a pogo stick. "My brother, Vanadi Yum," cried Chrome, "with bigger and better springs than ever. How are you, Van?" After the greetings, Van and Chrome and Al went aside and started whispering.

"What in the world are they whispering about?" asked Alice.

"Sh. They belong to the Ku Klux Klan," answered the pig, nervously.

"How do you know? Will they do anything to us?" asked Alice anxiously.

"They might. They're known as the three most prominent nitriding elements in the whole country."

The three approached. Alice was relieved to note that they appeared to be friendly, but the pig still seemed to be nervous.

"Would you like to go night riding with us on my pogo stick?" asked Van.

The pig tried to refuse on the grounds that he wasn't worthy to go riding with so many refined elements, but they insisted; and Alice also felt that she couldn't refuse. As soon as all were mounted, they went bounding off with such rapid and tremendous leaps that Alice was quite terrified.

"Don't you ever get tired?" Alice managed to ask.

"No," said Vanadi Yum, taking an especially big leap, "I never feel fatigue."

Just as they were coming down, many voices started crying in terror, "The boundary, the boundary! Help! Stop! Don't go over the boundary!" Alice looked down, and saw that they were indeed approaching the very brink of a precipice. Skillful night rider though he was, Vanadi could scarcely prevent another leap. As it was, they all fell down, tumbling to the very edge.

"What is that?" asked Alice, looking in horror at the yawning chasm.

"It's the grain boundary," explained Chrome. "If we had been precipitated down there, we could not have ever returned without having to undergo the most drastic heat treatment."

"Tell us about the time you were down there and some nifty carbon atoms held you tight," leered the pig suddenly at Chrome, who blushed at the memory of this youthful indiscretion.

"You're sillier than Silly Con," answered Chrome angrily, referring to Alloyland's old scavenger and street cleaner, an invaluable though little-noticed citizen.

"And the whole country was attacked by the Agents, just because you weren't there to defend it."

"You're cracked," said Chrome; "you don't know what you're talking about."

"And Columbi Yum saved things in the nick of time by locking up the carbon," chimed in Vanadi Yum. Judging from Chrome's embarrassment, Alice suspected that there was a good deal of truth in what they were saying, but even she could see that the poor pig was indeed cracked by the impact of their fall. She wished for his own sake that he had been the White Knight,* who survived many such falls.

*The White Knight, an inventor who made impact tests on his specially designed armor by falling off his horse and dropping weights on his toes. Lewis Carroll, loc. cit.

"Blast you for an atheistic crackpot!" cried Chrome, losing his temper.

"Yes, blast him. In the blast furnace with him," cried a number of religious fanatics who had been attracted by the argument.

"But you can't convert him by putting him in a blast furnace," objected Chrome.

"Into the bessemer converter, then," shouted the proselytizing alloys.

"I hope the government won't permit you to torture a poor pig in a bessemer furnace," protested Alice.

"Politically," replied Chrome, "our country is committed to the Open Hearth Policy, but this is a religious matter involving the conversion of an infidel pig."

"What is your religion?" inquired Alice.

"We are the Eternal Pantheists. We believe that pots and pans will last forever when made of the Perfect Alloy. Pots and pans are symbols of the Universal Container — the supreme metallic Unity containing a Diversity of Alloying Elements."

"Ha, ha, ha," interrupted two new voices.

Riding overhead on a huge magnet, two figures were swinging down toward the pig. The newcomers proved to be Silly Con and a Kobold — a brownie or a gnome — the first one Alice could remember having seen. They were both laughing, and Alice was much attracted by them, as she could sense that they were magnetic personalities. The Kobold was reciting one stanza from a poem entitled:

Ferrowocky

'Twas pig iron when Brinell and Ehn
Did Spiegel, graphite, and briquet
And all the irons enlarge the grain
But Chromium not yet.

Chrome then helped Silly Con and the Kobold attach the magnet to the pig, who was hoisted aloft and conveyed to a glowing cupola for melting.

"In spite of myself," grunted the pig, "I'm going to become refined."

"We won't associate with you till you are," said Van. "Drop him in." By this time all the Alloys of Alloyland had hurried to the scene and as the pig disappeared, they began chanting in religious frenzy.

"No hard feelings any more," responded the pig, who felt himself becoming momentarily softer and softer.

Alice turned her back on the cruel sight, for she had no desire to see the immolation of the poor pig. She was comforted, however, by the thought that he had gone to a bessemer land.

"What about Alice?" cried a voice.

"Put her on the pogo stick, and bounce her over the grain boundary," answered another. Before she could do anything about it, rough hands had seized her, and the order was obeyed.

"It's too deep for me," she shuddered to herself as she sailed over into the chasm.

She was really too frightened to glance back, but from the shadows that flickered around her in the red glow, it appeared that all the alloys were moving in a strange folk dance to the brink of the furnace and hurling themselves in to mingle with the molten pig — supreme martyrs to Destiny and the achievement of the Perfect Alloy. Soon the shadows disappeared and the chanting ceased.

* * *

"It's still too deep for me," she said the next day, as she wondered about her experiences. For a long time it seemed to her that she could still hear the Song of the Alloys:

Solo:

How doth a little ferr'-alloy
Improve the shining steels
And make machinery a joy
With wear resistant wheels!

Chorus:

Hail, Alloyland, the free,
Hail our mighty nation,
Hail, strength, ductility —
We still defy abrasion!

Solo:

Resisting atmospheric stain
And chemical corrosion
On land or sea or speeding plane —
In pumps we fight erosion!

Chorus:

Hail, Alloyland, the free,
Sing aloud this air,
Hail, strength, ductility —
And down with rust and wear!

Each year some prominent and active American metallurgist is asked by the American Society for Metals to give a lecture on some aspect of metal progress. This lectureship was established in honor of Edward deMille Campbell, a courageous and inspiring teacher at the University of Michigan, shortly after his death. This year the honor fell to James P. Gill, metallurgist of Vanadium-Alloys Steel Co., one of the brilliant young men who have delved into the ancient mysteries of the tool maker's art. He shows how the distribution of excess carbides in high speed tool steel should be controlled by forging and heat treatment to give the best cutting tools, and how the atmosphere in the heating furnace affects the temperature of the tool before quenching and hence its eventual grain size.

HIGH SPEED TOOL STEEL

BY JAMES P. GILL

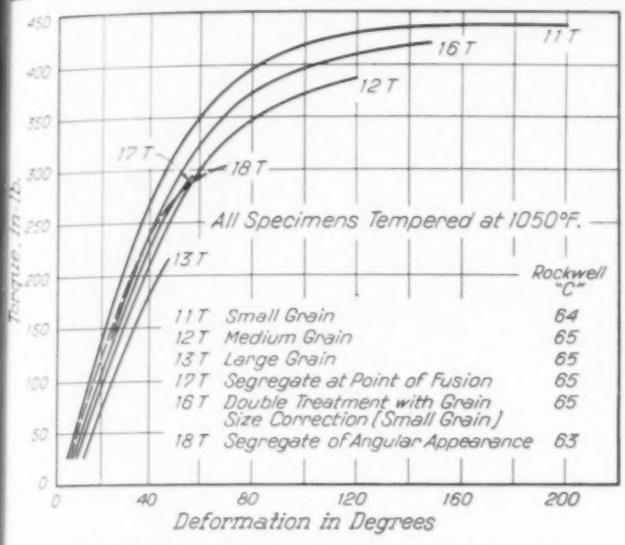
TODAY I will talk on the subject of high speed steel, a material which has an economic importance far in excess of the amount produced or of its monetary value. It is a complex material, so its behavior offers many opportunities for study and investigation. I shall deal only with one composition of high speed steel, namely, a steel containing almost exactly 0.70% carbon, 18% tungsten, 4% chromium, 1% vanadium and with about 0.25% of manganese and 0.30% of silicon. The characteristics of a steel represented by this analysis will be found to varying degrees in all types of high speed.

The Carbide Segregate

A photomicrograph of high speed steel in any condition will show particles of an excess constituent, commonly called the "carbide segregate." It is generally assumed that this segregate has a pronounced effect upon many of the characteristics of steels in which it occurs, but most investigators have been primarily interested in determining its composition rather than the effect it exerts upon the physical properties of the steel.

It is common knowledge that this segregate varies in size and distribution from the outside to the inside of the ingot, and that the distribution is influenced by many factors. It is also generally agreed that this segregate can only be distributed or broken up by mechanical work which causes it to elongate and break apart in the direction of working. It is also known that there is a direct relationship in the size and distribution of this segregate when comparing the structure of the bar with the structure of the ingot from which it was made. In the original paper some micros are shown indicating that the segregate may have a variable distribution determined by ingot size, mold design, casting temperature, rate of cooling and by degrees of mechanical work, but the individual particles may have a variable form, either quite spheroidal or having a mixed spheroidal and angular appearance. A completely angular appearance is unusual, but when it appears it cannot be readily broken up by mechanical work. A par-

tially angular appearance is not unusual and it will be shown how such a structure tends to affect the properties and behavior of the steel. Here it may be mentioned that high speed with angular segregate will harden only to Rockwell C-62 or C-63 when quenched and tempered, as compared to C-65 or C-66 for annealed high speed with spheroidal segregate.


Torque, In. Lb.
Deformation in Degrees
All Specimens Tempered at 1050°F.
Rockwell "C"
11 T
16 T
12 T
17 T
18 T
13 T
11 T Small Grain 64
12 T Medium Grain 65
13 T Large Grain 65
17 T Segregate at Point of Fusion 65
16 T Double Treatment with Grain Size Correction (Small Grain) 65
18 T Segregate of Angular Appearance 63

Strength and Plasticity of High Speed Steel (as Determined by Stress-Strain Curve in Torsion) Vary With Microstructure of High Speed Steel of Equal Hardness

A number of investigators have displayed keen interest in the composition of this segregate. Westgren and Phragmen suggested the composition of Fe_3W_3C when the segregate is saturated with tungsten, and Fe_4W_2C when saturated with iron.

By the somewhat questionable method of dissolving the iron matrix in dilute hydrochloric acid, the segregate was obtained from a number of samples heat treated in different ways. Residues from the annealed material show a higher carbon, chromium and vanadium content than the residues from the hardened samples. The differential in carbon content between the annealed and hardened samples is indicative of diffusion of the carbon from the carbides to the matrix.

The residues were also analyzed by X-ray diffraction, and the photograms of all the residues were substantially the same and in agreement with those observed by Westgren and his associates for the principal carbide phase in high speed steels.

Filtrates from the quenched samples were cloudy, and on settling, these fine residues were analyzed by X-ray diffraction, but evidently were of colloidal size and gave no diffraction pattern. These filtrates analyzed about 65% tungsten and 0.41 to 0.68% carbon.

Since it did not seem certain that only one compound existed in the residue, a number of heats were prepared with variable carbon contents and the residues obtained. In three of them a new compound appears, and a comparison of its diffraction pattern with those reported by other investigators definitely shows it to be the compound Fe_2W.

It, therefore, appears likely that the carbide segregate is predominately composed of Fe_3W_3C, with probably small amounts of chromium and vanadium carbides, possibly a small amount of Fe_2W, and iron associated in an eutectic. The large proportion of Fe_3W_3C present in the structure justifies the use of the word "carbide" as applied to this segregate. Regardless of the structural condition of the steel, whether it is annealed or hardened, with the segregate in a spheroidal, angular or fused condition, the primary constituent of the carbide segregate remains essentially the same.

Effect on Physical Properties

Strength and plasticity of high speed steels can be varied over a wide range by only slight changes in grain size and in segregate distribution. These properties were determined, as suggested by Emmons, in a torsion test, wherein the torque in inch-pounds is plotted as the ordinate and the angular deformation or twist in degrees is plotted as the abscissa.

The figure shows stress-strain curves of some specimens treated in several ways and then tempered at 1050° F. for 1.5 hr. All were within the hardness range Rockwell C-63 to C-65. Specimen 11-T had a small grain and small spheroidal segregate; specimen 12-T a medium grain and small spheroidal segregate; specimen 13-T a large grain and small spheroidal segregate. A comparison of the strength and plasticity of these three specimens shows a direct relationship to grain size, the plasticity decreasing at a very rapid rate with increase in size of the grain. Specimen 16-T was given the same original treatment as specimen 11-T, then a stress relief treatment (which will be described later) and a second hardening the same as the original. It had a grain size substantially the same as specimen 11-T but appears definitely to

President Archer and President-Elect Bain Flanking Campbell Lecturer Gill — Evidently Congratulating Each Other on Mr. Gill's Selection. James P. Gill has been metallurgist for Vanadium-Alloys Steel Co. since 1920. He was educated at University of Missouri School of Mines and Metallurgy and at Columbia University, and has the degrees of bachelor of science, master of science and metallurgical engineer. He is likewise chief metallurgist for Anchor Drawn Steel Co. and Colonial Steel Co.

have lost some of its plasticity by the double treatment. Specimen 17-T contained a segregate which had been near the fusion point and, as would be expected, shows substantially no plastic deformation.

Specimen 18-T was treated to produce the segregate with an angular crystalline appearance and it is very brittle — more so than can be explained on the basis of the grain size of this sample. It would appear that the sharp corners and edges of the segregate in this form had a wedge-like effect, thereby making the material much less plastic. The tendency for the segregate to assume this form is somewhat proportional to the temperature and time at temperature; long heating for any purpose, even annealing, may affect the physical properties in the final product. Thus, homogenizing treatments given to high speed steel, essentially for the most desirable purpose of breaking up the cored structure, will tend to place the segregate in an angular form, thereby inducing brittleness or lack of plasticity.

Quenched specimens, not tempered, Rockwell C-65, C-66, or C-67 hard, show almost no plastic deformation, undoubtedly due to the stresses that remain after quenching, but even in this condition the specimens show a relative strength very similar to that after tempering, as shown in the figure on page 43.

The thermal conductivity of high speed steel is of importance, since the failure of a tool is often the result of the softening of the cutting edge from the temperature to which it may be heated; the rapidity with which the steel will conduct heat from the cutting edge will have a considerable effect upon the rise in temperature at the cutting edge, which in turn affects tool life. Experiments on specimens prepared to have different microstructures, as above, indicate that variations in size, shape and agglomeration of segregate do not materially affect the conductivity.

Hot Hardness

A most important physical property of high speed steel is its ability to retain its hardness at elevated temperature, the so-called "red hardness" or "hot hardness." A number of efforts have been made to determine this property of high speed steel, which as a whole were rather unsatisfactory until the investigations of Harder and Grove using a method known as "mutual indentation." The results were presented in a paper at the New York meeting of

the American Institute of Mining and Metallurgical Engineers in February, 1933. Their conclusions were that the hardness of high speed steels at elevated temperatures shows a definite relation to the cutting properties of the steels when used in production.

Since the work of Harder and Grove seems to attach much significance to the property of "hot hardness," a number of specimens were prepared of exactly the same composition of an 18-4-1 high speed steel. The specimens were prepared to the exact size suggested by Harder and Grove and were tested at the Battelle Memorial Institute, using the identical equipment and procedure as described in the paper mentioned. These tests were made at 1200° F., and Dr. Harder found that the hardness, computed as in the Brinell test, varied from 338 to 415 depending on the history of the specimen.

"Hot hardness" increases directly with increase in grain size; the smallest grain showing an average for both quenched and drawn specimens of 342; the medium grain an average Brinell hardness of 390 and the very large grain an average Brinell hardness of 410. The specimen which was quenched from the point where the segregate is just beginning to fuse in the grain boundaries, which also had a very large grain, is substantially of the same hardness as the specimen treated to produce a large grain without fusion of the segregate. The specimen which was quenched from the as-rolled condition and which shows a grain size intermediate between very small and medium, shows an average hardness of Brinell 369, exactly where it should be in accordance with its grain size.

The specimen having an angular segregate was unique, for it showed an average hardness of Brinell 335 in the as-quenched condition — the lowest of any of the specimens — but in the tempered condition a hardness of Brinell 388.

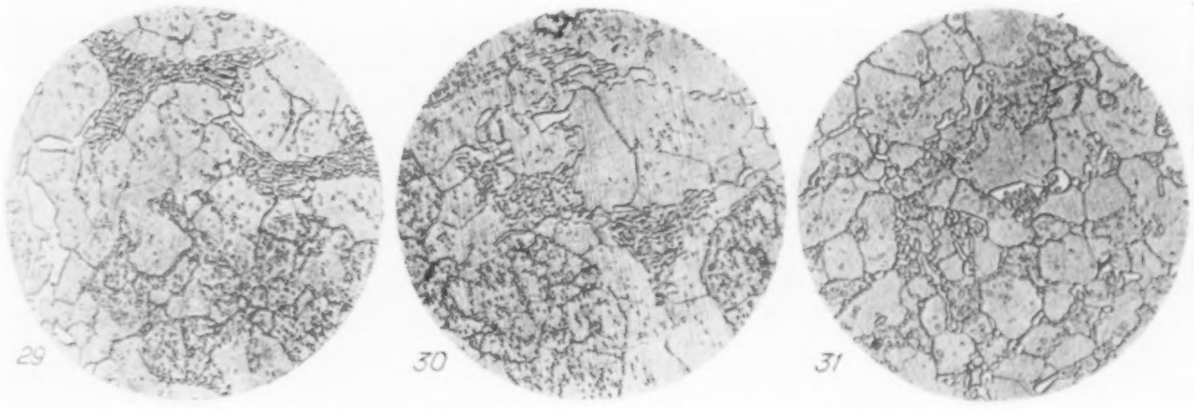
These results are consistent with cutting tests, for so long as the cutting edge does not chip (brittleness induced by the large grain) the tool will usually show a longer life. This is based on the assumption that the tools are given a single quench to produce the increase in grain size, which also means that the time or temperature is increased as the grain size is increased. When the large grain was produced by several quenchings from the same temperature, given an anneal and then quenched, the "hot hardness" of the specimen was not nearly as great as when the grain was grown in a single quench.

Effect of Segregate on Grain Size

To determine whether the grain size developed on hardening was a characteristic of the heat of steel from which the sample was taken, tests were made from heats varied in a number of items (scrap, double slags, deoxidizers), but no measurable difference was discovered.

Grain size in small tools does not increase as rapidly during conventional heat treatments as in larger tools, but this may be explained by the fact that in hardening specimens they are held in the high heat of some 2350° F. for only a few minutes and there is an appreciable temperature gradient between the outside and inside of the specimen at the time of quenching.

In order to obtain samples having the seg-



Photomicrographs at 500 Diameters Taken From Different Depths in Forged 8-In. Billet, Showing Effect of Uniformity and Fineness of Segregate Distribution on Grain Size. Micro 29 is 1 in. from surface, 30 is halfway to center, 31 is at center

regate distributed in particles of about the same size entirely across the section, pieces were cut from a forged billet 8 in. square, one sample taken 1 in. from the outside, the second halfway between the center and outside, and the third from the center. The three specimens were treated at the same time by quenching from a temperature of 2350° F. (1285° C.). The respective micros 29, 30 and 31 (page 45) taken at 500 diameters, show definitely that the grain size is the smallest in those areas which have the most uniform and finely divided segregate. No. 30, taken of the specimen halfway to the center, is an excellent example of the restraining influence of the segregate on grain growth, since in the areas having the finely disseminated segregate the grain is considerably smaller than in the surrounding areas having only a few large particles. This appears to be good evidence that the segregate mechanically obstructs grain growth.

This same effect was shown by studies on pressed bars of carburized iron (prepared from very pure iron carbonyl) with or without fine particles of tantalum carbide (shown to be practically insoluble in solid iron at all temperatures). Various heat treatments developed large grains, both microscopic and Shepherd fracture standard, in the carbon steel, but considerably smaller grain size when conditions were otherwise the same except that the steel contained fine particles of tantalum carbide. This large difference in grain size seems a most conclusive bit of evidence upon the mechanical restraining effect on grain growth of carbide particles imbedded in the material.

"Fish Scale" After Repeated Hardening

It is well known that the re-hardening of high speed steel, when performed under certain conditions, results in the steel having a so-called "fish scale" or "marble" fracture. Brophy and Harrington have apparently established that the abnormal grain growth which causes such a fracture results from straining, and that there is a direct relationship between the size of the grain and the degree of stress existing in the steel at the time of reheating for hardening. They also pointed out that when the material is highly stressed such stresses must be removed by annealing for extended periods of time to prevent abnormal grain growth.

Rate of heating through the recrystallization range (1375 to 1440°F.) is probably the controlling factor. Some oil-quenched specimens were therefore given a stress relief treatment as follows: Temperature increased 25° F. each 30 min. in carrying up through the range 1375 to 1450° F. After this slow heat they were transferred to a preheat furnace at 1550 and high heat at 2350° F. and quenched in an ordinary way. A single treatment of this sort did not affect the grain size as indicated by fracture and micrograph. Slight "fish scale" and mixed grain size appeared after the third repetition of this stress relief heating followed by quenching. Even slower heating in a wider range, 1325° to 1450° F. developed "fish scale" after the fifth repetition.

Assuming that stresses are the primary cause of the abnormal grain growth, then apparently our procedure of stress removal did not quite remove all of the stresses in specimens of this size. Our experiments show clearly that stresses are much greater near the center of the specimen than toward the outside and that it would undoubtedly be more difficult to remove such stresses with an increase in the size of the specimens. It is also likely that the temperature and rate of grain germination may be influenced somewhat by the degree of stress that exists at the time the specimen is heated.

Effect of Furnace Atmosphere

It is important, in the hardening of fine edged tools, to heat them in such a manner that the fine cutting edges will not be damaged. For many years it has been known that furnace atmospheres materially affect the surface of high speed steel when heating for hardening. Furnaces with controlled atmospheres have been developed primarily to produce a better surface on hardened tools. Shortly after this it was noted that in certain atmospheres the steel could be held much longer at the hardening temperature without material grain growth. Tour, and Phillips and Weldon published papers on this phenomenon. Their deductions were practically the same, namely, that the gases surrounding the steel during heating for hardening did in fact materially affect the grain size as well as the temperature at which the carbide segregate would fuse.

About four years ago the speaker at first agreed, but when attempting to check his results in a different furnace and with gases synthetically mixed, different results were obtained. Further investigations led to the conclusions

that the gases surrounding the steel were materially affecting the temperature of the steel as well as the time of heating. A number of investigators have taken exception to these conclusions and for this reason experiments were again made to show that by varying the composition of the gas, a change could be made in the rate of heating. The first group of samples was treated in a controlled atmosphere furnace. The samples were machined by removing $\frac{1}{8}$ in. of surface to give a cylindrical bar 2 in. diameter by 2 in. long; a $\frac{11}{32}$-in. hole $1\frac{1}{4}$ in. deep was drilled longitudinally in the center. Three thermocouples were used, one inside the specimen, another flat against the surface of the specimen; the third was the furnace control couple located about 6 in. above the hearth. The temperature of the hearth was taken immediately before placing the specimen in the furnace and immediately after its removal. New thermocouples were used for each specimen, and temperature readings were taken every 30 sec. All the specimens were preheated alike in the same furnace and for the same period of time, which was 35 min. at 1550° F.

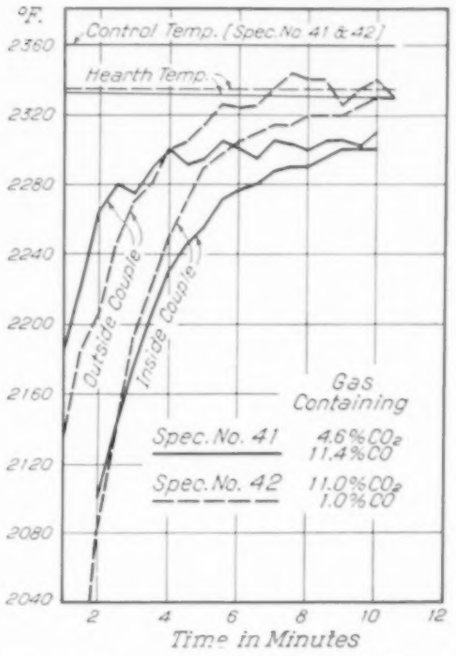
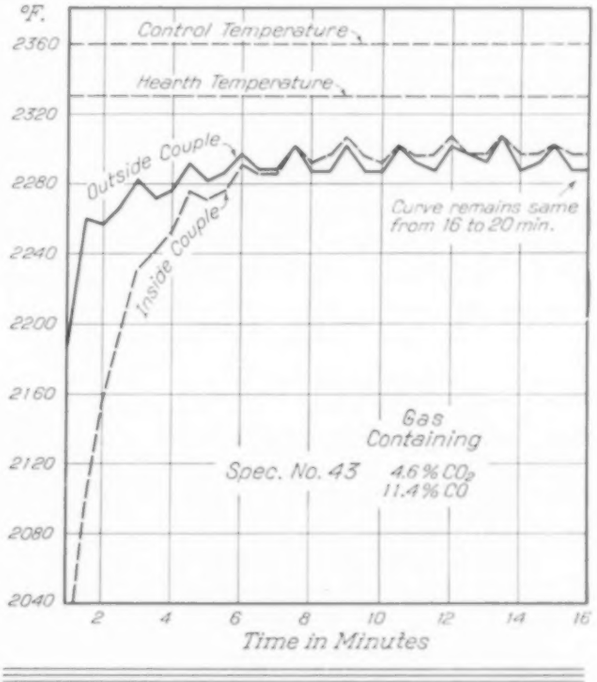


Fig. 42 (Above) Shows That High Speed Steel Specimens Heated in Atmosphere With Excess CO_2 Reach Hearth Temperature Much Quicker Than in CO. Fig. 43 (below) indicates that in latter case even 20 min. (double time) is insufficient

Oxygen Causes Self-Heating

For the first two specimens (No. 41 and 42) the temperature control was set at 2360° F. An atmosphere containing 4.6% CO_2 and 11.4% CO was used for specimen 41 and an atmosphere of 11.0% CO_2 and 1.0% CO was used for specimen 42. The results, at the top of this page, definitely show that the specimen heated in the gas containing the greater percentage of CO_2 rose in temperature more rapidly and attained a higher temperature. Specimen 41 never reached the hearth temperature, while specimen 42 did.

Possibly specimen 41 had not been held a sufficient length of time so specimen 43 was heated in the same atmosphere and held 20 min. with the result shown below; again the specimen did not become as hot as the hearth. By experiment a temperature was selected so that specimen 41 could be heated at the same rate and to the same temperature in a gas containing 3.8% CO_2 and 11.6% CO as specimen 42, which was heated in 11.0% CO_2 and 1.0% CO. It was found that the control should be set at 2390° F. to obtain this heating rate. Figure 44 (page 48) shows a comparison of the temperature readings. Photomicrographs on page 48 taken halfway between center and outside of these specimens show no noticeable difference in grain size. Hardness of the two was exactly the same, namely, Rockwell C-66. Similar experiments were made using the same furnace with about the same atmosphere but varying the temperature and in every instance the results obtained were very similar to those described and illustrated here.



It must not be inferred from these experiments that the amount of CO and CO_2 gases present *alone* determines the rate of heating. It is possible to keep the amount of CO and CO_2 gases constant and yet vary the rate of heating by a change in the composition of the remainder of the gas.

If atmospheres *do* affect grain size then it should be noticeable with radically different atmospheres; to test this, additional experiments were made. A quartz tube was used for the heating chamber, through which were passed, in different experiments, pure CO, pure CO_2, and air. When the tube temperature was maintained at 2340°F. the center of the specimen heated in CO did not reach tube temperature in 20 min., in CO_2 it reached tube temperature in 12 min., while the specimen heated in air only 5 min. far exceeded the tube temperature both on the inside and outside. This specimen plainly shows self-heating or heating from oxidation. All three had substantially similar grain size at the center of the sample in the respective times.

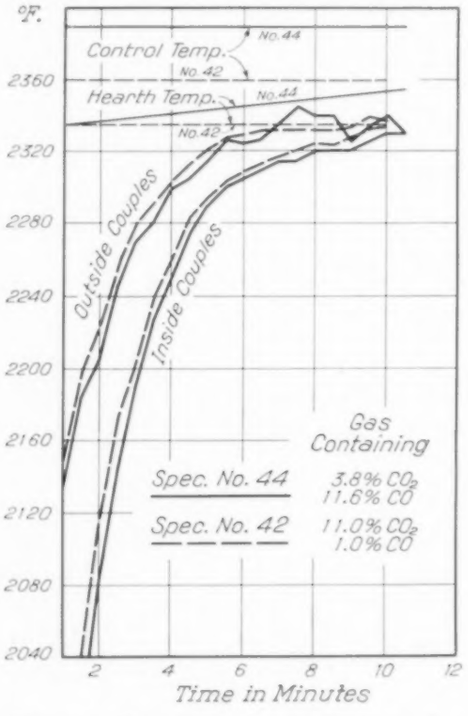


Fig. 44 — Furnace Controls Must Be Set Much Higher When Heating High Speed in an Atmosphere With Excess CO Than With Excess of CO_2 So That Steel May Reach Equivalent Temperatures in 10 Min.

4. The thermal conductivity is not materially affected by the grain size or by the distribution and form of the segregate.

5. The hardness at elevated temperatures is materially affected by grain size and by the outward appearance of the segregate. The distribution of the segregate is of inferior influence.

6. The susceptibility to grain growth is not a characteristic of the method used in melting the charge and deoxidizing the steel — that is to say, of normal variations in good steel making practice.

7. The carbide segregate which is not dissolved in solid solution in the steel mechanically obstructs grain growth of the austenite.

8. The stresses which result from the initial hardening of high speed steel require a considerable length of time for removal at comparatively low temperatures. The stresses when fully removed will only slightly affect the physical properties of the steel on rehardening.

9. The grain size of the steel is affected by the composition of the furnace atmosphere surrounding the steel during hardening, only as the composition of the gases affects the rate of heating and the temperature of the specimen.

Summary

1. The carbide segregate in an 18-4-1 high speed steel is not materially changed in composition by heat treatment, by distribution or by outward form.

2. The outward appearance of the carbide segregate seems to influence the rate of diffusion and the hardenability.

3. The strength and plasticity of high speed steel is materially affected by the grain size, by the distribution of the segregate and by the outward form of the segregate.

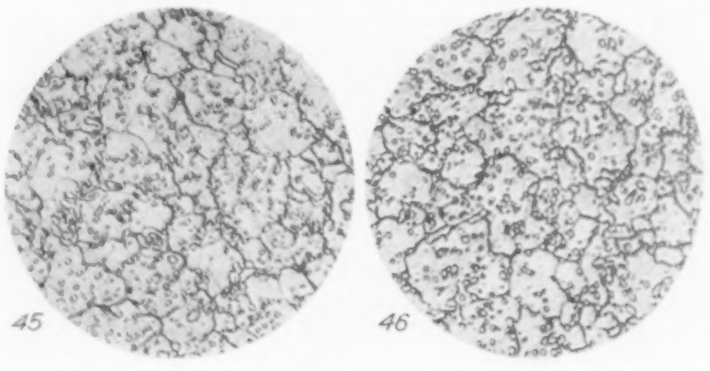


Fig. 45 and 46 — Grain Size of High Speed Steel Is Substantially the Same if Samples Are Heated to Same Temperature. Micro 45 corresponds to Specimen 44 in Fig. 44 above, and Micro 46 to Specimen 42

We are glad to welcome a new correspondent to these columns, arrangements having been made for periodic letters from J. H. G. Monypenny of Sheffield, England. Mr. Monypenny is connected with Brown Bayley's Steel Works, Ltd., a leading British manufacturer of high grade steel. He is one of the pioneer investigators of the high chromium and nickel alloys, and his book on "Stainless Iron and Steel" is authoritative

FOREIGN LETTERS

Unexplained Anomalies in Creep Stress of Various Carbon Steels

SHEFFIELD, *England* — In England, as in other countries, the behavior of steels at high temperatures forms the basis of many investigations. Interest centers particularly in that range of temperature — 650 to 1000° F. — which is of importance in modern steam plant. The desire to increase steam temperatures for the sake of greater efficiency is in the minds of most designers of power plant, and consequently there is a very real demand for reliable data showing the combined effect of these high temperatures and of stress on steels which are suitable for plant construction.

It is now some years since the idea of a "limiting creep stress value" was propounded, and in the meantime many determinations have been made of the creep stress values of various steels. A study of all this work — admittedly of very great value — indicates very definitely, however, that the behavior of steels in the above mentioned temperature range is very complex and that the load carrying capacity of a particular steel, while so heated, depends on many factors, some of which are still unknown. The truth of this statement may well be appreciated by reading the paper on "Some Aspects of the Behavior of Carbon and Molybdenum Steels at High Temperatures" by Jenkins, Tapsell, Mellor and Johnson, which was presented in June to the Chemical Engineering Congress in London. There is much of interest and importance in this paper but attention may be directed to the first part of it dealing with carbon steels, as it has a direct bearing on the statement made above.

Thirteen steels were tested, six of which had a nominal carbon content of 0.15% and the remainder of 0.40%. Creep tests were carried out at 840° F. under a stress of 18,000 psi. and the rates of creep of all the steels measured at the end of 20 days. Four of the mild steels behaved in a similar manner — that is, at the conclusion of the test, they were creeping at an average rate of 0.8×10^{-6} per hour. The other two mild steels were relatively much weaker, their creep being respectively 13 and 135 times as great.

A similar variation was found in the higher carbon steels. Six of these gave results of the same order, their average rate of creep being 1.4×10^{-6} per hour. This value, it may be noted, is higher than the average value for the normal steels containing 0.15% carbon which, in itself, provides much food for thought. The seventh steel behaved abnormally; its creep rate was 18.5×10^{-6}, a value thirteen times greater than the average of the other six.

It should be emphasized that all the steels were normal products of the acid openhearth, basic openhearth and basic electric arc furnaces, and lest it be thought that the steel making process was the deciding factor, it may be noted that of the three steels possessing abnormally

fast creep rates, one was made in each type of furnace. Determination of the oxygen contents of the steels failed to indicate any reason for the difference in creep strength, nor could the latter be linked up with the response of the steels to the McQuaid-Ehn test; microscopic and macroscopic examination also gave no evidence which would account for the high rate of creep of the three weak steels.

These tests were carried out on normalized material and although different heat treatments affected the actual creep rates of the steels, the three weak steels exhibited relatively high creep rates under all conditions.

It appears, therefore, that two different casts of mild steel, having substantially the same composition and similarly heat treated, can exhibit widely different behavior when tested at 840° F. and that the reason for this is still obscure. The fact that such abnormality may occur makes it highly desirable that some type of rapid creep test be devised which will distinguish with certainty between steels having normal and abnormal creep properties, and yet may be carried out so expeditiously that it can be applied as a routine or inspection test to each cast of steel intended for use at high steam temperatures.

One wonders, also, whether this unusually low resistance is confined to ordinary carbon steels or whether it may also be found among the many alloy steels that are being used because of their greater "strength" at high temperatures. If the latter be true, the problem confronting metallurgists and engineers interested in plant operating at such temperatures, is indeed a thorny one.

J. H. G. Monypenny

Forged Versus Cast Crankshafts

SCHWEINFURT, *Germany* — Under certain detrimental conditions of design or service the endurance of machine parts is often so greatly reduced that fatigue failure results. To avoid such predictable failures, some parts of important machines are regularly replaced after a certain number of hours in operation. For security and economy, therefore, an increase in the endurance of such parts is much to be desired. This may be done either by constructional measures, such as improving the strength-distribution of the part, or by prior cold working of the critical section.

Crankshafts are especially susceptible to fatigue failure, because of the abrupt transition in the flow of energy from the journals and connecting rod pins to the cheeks. These transition zones may be considered as notches which cause the endurance in large crankshafts made of carbon steel (70,000 psi. ultimate tensile strength) for instance, to be only about 10,500 psi., as indicated by statistical studies of fractures in diesel motors. By thorough, systematic observation of fracture surfaces and locations it is possible to redesign to relieve somewhat the endangered places, as noted above.

One method used to search for causes of fatigue failure in long aircraft engine crankshafts is to study the resonance of torsional vibration. Shorter crankshafts for automobile engines are of a deeper torsion type, and failure in bending therefore predominates.

The above conclusions of Prof. A. Thum (recently presented at the 74th convention of the Verein Deutscher Ingenieure at Darmstadt) were experimentally verified by endurance tests on single-throw crankshafts made of steel, pearlitic cast iron and black heart malleable iron, conducted in the materials testing laboratory of Darmstadt Technical College.

The torsional endurance limit was first investigated by preliminary tests on small crankshaft models made of 70,000-lb. machine steel. Journal bearings and connecting rod pin were 0.55 in. diameter, throw was 0.98 in. and clearance between cheeks 0.59 in. Using a Schenk torsion machine and properly finished cylindrical specimens, the endurance limit of this steel was found to be about 28,500 psi. Because of the quasi notches — that is, the transition from the pin and journals to the cheeks — and because of a 0.060-in. oil hole, the endurance of the model shaft was reached at a torsional stress of only 20,000 psi., indicating that the natural endurance of the steel was reduced about 30% by the unfavorable shape. When more oil passages were drilled, corresponding to the usual number in crankshafts, the torsional endurance stress was reduced to 14,000 psi. — in other words, the normal endurance of the steel was reduced 50%.

After these preliminary experiments, torsional endurance tests, using a very interesting special test procedure, were undertaken on full-sized crankshafts for four-cylinder automobile engines of three different designs. Crankshaft pin diameters were 1¾ in. more or less; in two designs these were hollow bored, in one they

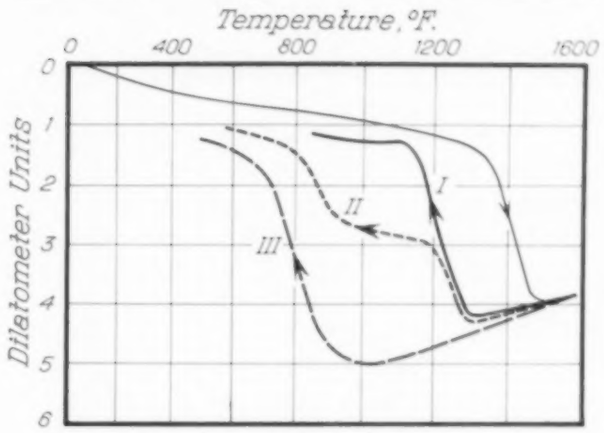
(Continued on page 100)

Some Observations on Flakes

DENAIN, *France* — Numerous theories have been presented concerning the nature and origin of flakes, and in the final analysis, although certain of them carry some weight of truth, none appears to offer a complete explanation. While the latest theories concerning the evolution of gas, particularly hydrogen, explain phenomena otherwise inexplicable, and although the evolution of gas in a solidified steel may be the principal cause of flake formation, we hesitate to admit that it can be the *only* cause. It seems to us that if evolution of gas were the only cause of flakes, this defect would be much more common than it is.

Stresses created by evolution of gas may frequently be insufficient to cause fracture, but flakes may still occur if thermal strains are also present or if local heterogeneities create zones of weakness which are the starting points for internal cracks.

Flakes do not occur in various types of steels with the same frequency and same dimensions nor with exactly the same appearance. Thus, the largest and most typical flakes seem to favor steels corresponding to the dilatometric cooling curves of Type II and III shown in the figure above, that is, with a stepped or a suppressed transformation while cooling at an average rate of 30° per min. between 1600 and 700° F. On the other hand, flakes are found only rarely in carbon steels and nickel-chromium structural steels corresponding to Type I curve. When they do occur in the latter steels, they take the form shown in the left sample in the photograph; that is, tiny bright points up to 4.0 mm. in average diameter.



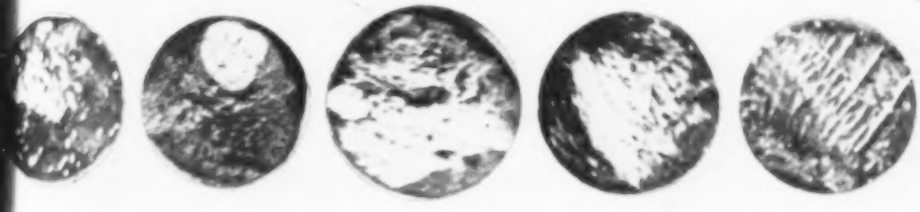
Steels With Cooling Curves of Types II and III Are More Subject to Flakes Than Those of Type I

In steels that are subject to flakes, their diameter is considerably larger, sometimes reaching several centimeters (second sample from left). However, with proper precautions in fabrication large forgings can be made with very high transverse mechanical properties, such as required by the French Navy for alloy steel pinions in reducing gears.

Another interesting feature is this: Chromium-molybdenum steels used for large forgings with 0.15% C, 0.30% Mo, and 0.35 to 0.60% Cr, show less tendency to flakes when made in an acid furnace; basic steels require much more care in forging.

The fact cited by Messrs. Musatti and Reggiori that flakes are much more frequent mid-way than at the center of the piece is not evidence against the effect of chemical segregation and inhomogeneities of other kinds in the ingot, for it is really at this point that unoriented dendrites and inverse segregations are localized.

On the other hand, it should be noted that very pure steels (from the standpoint of phosphorus, sulphur and oxygen) present a mark-



Flakes and Analogous Defects, Magnified 2 Diameters

Left to Right: (a) Very small spots resembling flakes found in steels only slightly subject to this defect. 0.30% C, 0.45% Mn, 3.0% Ni, 0.55% Cr

(b) Typical flake of small size. Steel contains 0.22% C, 0.30% Mn, 2.7% Ni, 0.50% Cr, 0.30% Mo

(c) At the end of the ghost line is a round spot strongly resembling a flake. 0.26% C, 0.40% Mn, 1.97% Ni, 0.48% Cr

(d) Dendritic spot with silvery area. 0.35% C, 0.40% Mn, 1.10% Ni, 0.41% Cr

(e) Geometric figures almost always found in fractures containing flakes. 0.27% C, 0.38% Mn, 2.9% Ni, 0.57% Cr, 0.39% Mo

edly dendritic primary structure, and this is reflected in the secondary structure by heterogeneous distribution of carbon. For instance, if the secondary structure of a flaky Ni-Cr-Mo steel is developed after reducing to one-fifth the original size by forging, quenching and tempering, polishing a section, etching with picric acid and magnifying 25 diameters, it will show heterogeneous sorbite — a cloudy appearance clearly suggesting the dendritic structure. Baboscin's viewpoint that dendritic segregation is an important factor, should therefore not be neglected in seeking a cause for flakes.

I believe the similarity to flakes of certain defects due to segregations should be pointed out. The central sample shows a rectilinear vein of segregations (ghost line) ending in a white spot which could be easily confused with a flake. The one next to the right end is of a steel not subject to flakes but containing a white dendritic spot having the same silvery shine as flakes have.

Finally, a characteristic common to fractures of samples containing either small or large flakes is that they are often accompanied by geometric figures related to the dendritic forms of the type shown in the last sample at the right-hand end.

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Chief Metallurgical Engineer
Anciens Etablissements Cail

IMPROVED TOUGHNESS IN QUENCHED ALLOY STEEL

MOSCOW, *U.S.S.R.* — A novel heat treatment of structural alloy steels has been investigated in the physical laboratory of the Research Institute for Aircraft Materials by my associates M. F. Bessudnowa and L. E. Pevsner. In order to obtain the best combination of high strength and toughness these engineers quenched the metal from rather high temperatures and followed this with a low tempering.

There persists an opinion that when the hardening temperature is increased considerably above Ac_3 point, the hardened steel is embrittled — but in some cases this opinion is not justified. This can be concluded from much work already published.

For instance, Chabachpashev and Sheinin showed that the impact strength of many alloy steels is not only unimpaired but is considerably increased by quenching from higher than usual. According to these investigators, the increase of impact strength is explained by an increased amount of residual austenite which is not decomposed during the following low tempering. They believe that the heterogeneous mixture of residual austenite and transformed martensite gives the desired combination of high toughness and strength.

However, detailed investigations of hardened carbon steels by the magnetic method (by Steinberg, Esser and Mikami) showed that the amount of residual austenite in the quenched hypo-eutectoid steels is not changed with increasing the hardening temperature, and even though the amount of austenite in hypereutectoid steels *does* increase with the first increase in hardening temperature, it reaches a maximum value and then decreases.

According to still other workers (Maurer and Schroeter) the amount of residual austenite remains approximately constant with varying the hardening temperatures even in the case of the hypo-eutectoid steels containing a moderate amount of alloying elements.

In order to clarify this matter, we carried out a detailed investigation of residual austenite in four medium carbon steels of the following analysis: Nickel-chromium steels with 3.0 to 4.0% Ni and 1.0 to 1.5% Cr; nickel-chromium-molybdenum steels with 1.0 to 1.5% Ni, 0.5 to 1.0% Cr, 0.2 to 0.3% Mo; nickel-chromium-tungsten steels with 3.0 to 4.0% Ni, 1.0 to 1.5% Cr, and about 1.0% W; and a chromium-silicon structural steel. The intensity of magnetization at saturation was determined, which is proportional to the quality of ferromagnetic phase in the specimen. In none of the steels investigated did the amount of residual austenite change with an increase of the hardening temperature in the 1475 to 1830° F. range. In other words, these alloys behave like plain carbon steels.

An investigation of the impact strength of these same steels showed a general increase of toughness with the increase of hardening temperature, if the oil hardened specimens were given a low draw. Furthermore, the nickel-chromium-tungsten and nickel-chromium steels also showed this phenomenon even in the oil-hardened state before tempering. Nickel-chromium-molybdenum steel increased in toughness with higher quenching temperature only when the specimens were tempered at 300 to 400° F., yet the amount of retained austenite after this tempering was nearly unchanged.

The curves on page 98 show the relation between impact strength, *(Cont. on page 98)*

Grain Size and the McQuaid-Ehn Test

PARIS, *France* — The question of grain size, which originated and has been extensively studied in the United States, has not been ignored in France. At the Aciéries d'Ugine, for instance, the method of determining residual or metallic aluminum in steel has been improved to such an extent that it is possible to detect accurately percentages as low as about 0.010%. As noted by McQuaid in his last paper, there is a relationship between the refinement of the grain and the presence of aluminum so revealed.

The effect of the aluminum depends on the state of oxidation of the metal at the moment when the addition is made, and varies with the manufacturing technique and the time of the addition; for a given quantity of added aluminum, its effect on grain refinement will decrease as the addition is made in the ingot, in the ladle, or in the furnace respectively. To obtain satisfactory results, the procedure must be such as to arrive at a known, low degree of deoxidation in the steel so that a minimum amount of aluminum need be added. In this respect, the method of rapid deoxidation by puddling with the proper slags (described in my letter to Metal Progress, February 1933) is apropos.

Other addition elements besides aluminum may be used to refine the grain, such as titanium, vanadium, or tungsten, but their action is not yet well known and their effects on the properties of steel cannot be regarded as equivalent. Moreover, incorrect or premature generalizations must be avoided in the phenomena as well as in the definitions. Thus the terms "grain size" and "abnormality" have been accepted in current terminology with too absolute a meaning and too close a connection. In fact, grain size and abnormality depend, for a given steel, on the conditions of mechanical work (rolling program) and heat treatment *(Cont. on page 92)*

Pig Iron from Pyrite Clinker

TURIN, *Italy* — The use of calcined pyrites as a raw material for the production of pig iron is a problem of special interest to Italy, where the domestic consumption of iron and steel is rapidly increasing, and where large iron ore deposits are not numerous yet pyrite deposits are abundant. The present production of calcined pyrites, a byproduct of the chemical industries, corresponds to about 30% of the total consumption of iron ore. About half of our iron ore is produced by Italian mines, and the remaining 20% is still imported. It should also be remembered that we consume a relatively limited amount of pig iron, due to the fact that a great proportion of the steel is manufactured in electric furnaces, using mostly steel scrap, much of it imported from America.

During the last ten years calcined pyrites have been used after desulphurization in some Italian blast furnaces mixed with other ores. Only the highest grade of pyrite was used by the sulphuric acid plants; desulphurization and sintering were done with two well-known processes: (*a*) the Greenawalt sintering process, where a bottom layer of coarse and a top layer of fine particles of moistened iron-sulphide ore, flux and fuel are spread on tilting grate bars, ignited, and burned under a downdraft suction, and (*b*) the Cockerill briquetting process, where compressed bricks of pyrite are calcined in 12 hr. in a 225-ft. tunnel kiln at a maximum temperature of about 2400° F. In both cases desulphurization was practically complete, and the technical results were good.

But the fact that our existing blast furnaces are located near their ore deposits, far from the chemical plants, so that the iron companies had to pay extra transportation for the calcined pyrites, made it difficult for this last product to compete economically with the other ores.

However, a very conservative estimate shows that, by the utilization of pyrites with a slightly lower sulphur content (such as could conveniently be used, if their calcined residues could only be sold in this country, instead of being exported to distant markets at prices covering little more than the transportation cost) the total iron ore requirements of Italy could be furnished from domestic sources.

It was also evident that a rational solution of the problem could only be obtained by erecting special reduction plants, in places not too distant from the points where pyrite is calcined, and in industrial centers consuming large amounts of iron and steel. The first of these plants, designed especially for the treatment of calcined pyrites, has now been in regular operation for many months, giving excellent results. This plant is being enlarged, and will shortly be followed by others. It belongs to the large steel company Acciaierie & Ferriere Lombarde Falck, and is located near Milan, *(Cont. on page 96)*

The author, who is a member of the metallurgical staff of the International Nickel Co., Inc., at Bayonne, N. J., has made some tests to verify and supplement others in the literature, and finds that the important physical properties of Monel, as cast or forged, annealed or cold worked, either are unaffected or are improved at temperatures down to liquid air

PROPERTIES OF MONEL AT LOW TEMPERATURES

BY D. E. ACKERMAN

THE EFFECT of low temperatures upon the physical constants of metals has been an interesting and fertile field for scientific research for many years. Recently, however, the rapid commercial development of air transportation, domestic refrigeration, petroleum refining and condensed, liquid or frozen gases has created a need for an accurate knowledge of the mechanical properties of metals at *extremely* low temperatures, so that the proper metal can be selected for critical parts in which failure would be devastating.

To date relatively few reliable data extending to very low temperatures have been generally available, but a recent investigation of the properties of Monel at sub-atmospheric temperatures in the research laboratory of The International Nickel Co., Inc., confirms the scanty data previously available in demonstrating that this alloy has outstanding low temperature properties. The results of this investigation, together with a survey of the literature upon the subject, are reported in the present paper.

Experimental Materials

Several grades of commercial Monel were available. One heat was forged to 1½-in. square bars; some of these were air cooled from the forging temperature while the others were well annealed at 1750 to 1800° F. in a continuous furnace. (Both of these tempers are widely used in low temperature applications.) Two different grades of cast Monel were also tested. Commercially cold-drawn rod was used for a few impact tests. Finally, commercially welded plate was tested.

Analyses and room temperature tensile properties of these various materials are given at the top of next page. It was noted that, at room temperature, the elongation of the annealed samples was slightly lower when tested in the 0.200-in. diameter section, than when the standard 0.505-in. bar was used. Tensile strength of the annealed 0.200-in. test piece was 80,200 psi., proportional limit 24,100 psi., elongation in 2 in. 42%, and reduction of area 71%.

Testing at Low Temperatures

Conventional testing equipment was used. Tensile tests were made with the specimens and grip ends immersed in the cooling medium; temperature was controlled during the test by adding fresh coolant as required. Temperatures were measured by copper-constantan thermocouples and a potentiometer. At room temperature standard tensile specimens (2-in. gage

length, 0.505-in. diameter reduced section) were used, but to facilitate cooling, the specimens used at lower temperatures were machined with 2-in. gage length and 0.200-in. diameter reduced section.

Charpy specimens were notched with the standard V-notch transverse to the length of the wrought bars or cast specimens; welded specimens were notched parallel to the length of the weld.

All test specimens were quickly removed from the coolant for testing and the test was completed within three seconds after removal, which assured that the temperature rise during test was negligible. All specimens were held at temperature 30 min. before testing and generally duplicate or triplicate specimens were broken.

Test temperatures were attained by means of the following media: 32° F., ice and water; +10° F., ice and calcium chloride solution; −20° F., alcohol and solid carbon dioxide; −310° F., liquid air.

The second table, below, shows the effect of low temperatures upon the tensile strength and ductility of the two tempers of wrought Monel. Room temperature properties are repeated for ready comparison. Satisfactory equipment for measuring the strain of the reduced section while immersed in the coolant was not available but the yield strength may be expected to increase with the tensile strength.

Both forged and annealed Monel thus increase about 50% in tensile strength as the temperature is lowered from 70° F. to −310° F. yet they completely retain their respective room temperature ductilities. A number of ductile materials, including some steels, are available for use at moderately sub-atmospheric temperatures, but most of these become brittle as the temperature is progressively lowered, and the majority of those retaining high ductility at low temperatures suffer from a relatively low level of mechanical properties. Because of its excellent mechanical properties, which improve with decreasing temperature, and its high ductility, which is retained unimpaired to very low temperatures, Monel is an exceptionally economical material of construction for low temperature equipment.

Several independent investigations amply confirm the data reported above, as the table on page 58 shows. The work of W. J. DeHaas and R. Hadfield, reported to the *Philosophical Transactions* of the Royal Society, 1933, vol. 232, p. 297, demonstrated that the tensile strength and yield point of forged Monel continue to increase without impairing the ductility down to temperatures at least as low as −423° F. (only 36° F. above absolute zero). E. W. Colbeck and W. E. Mac Gillivray's data on proof stress support the former investigators' yield point value.

Analysis and Room Temp. Tensile Properties

	Wrought		Cast	
	Forged	Annealed	Regular	Grade "H"
Chemical Analysis				
Carbon	0.14	0.14	0.13	0.14
Manganese	1.07	1.07		
Iron	1.30	1.30	1.95	1.50
Sulphur	0.005	0.005		
Silicon	0.06	0.06	1.43	2.69
Copper	29.66	29.66	29.4	29.4
Nickel	67.74	67.74		
Tensile Properties (0.505-in. Specimen)				
Tensile strength, psi.	86,800	78,650	80,000	88,900
Yield point, psi.	64,800	31,300	37,600	56,800
Yield strength (0.1% set), psi.	—	—	36,300	54,700
Proportional limit, psi.	54,500	25,500	26,200	29,300
Elongation in 2 in., %	31.0	51.5	28.0	15.0
Reduction of area, %	72.5	75.0	34.0	27.9
Brinell hardness	171	127	135	190

Influence of Temperature on Tensile Properties

	At 70°F.		At 32°F.	At 10°F.	At -20°F.	At -310°F.	
	Forged	Annealed	Annealed	Annealed	Annealed	Forged	Annealed
	0.505-in. Spec.		0.200-in. Specimens				
Tensile strength, psi.	86,800	78,650	80,200	83,000	84,400	86,800	130,000	117,600
Yield point, psi.	64,800	31,300	—	—	—	—	—	—
Proportional limit, psi.	54,500	25,500	24,100	—	—	—	—	—
Elongation in 2 in., %	31.0	51.5	42	44	42	47	32	50.7
Reduction of area, %	72.5	75.0	71	—	—	—	72	75.3

Confirmatory Data on Strength and Ductility at Low Temperatures

Test temperature, °F.	Room	32	14	-4	-40	-76	-103	-112	-184	-292	-423
Experimenters: W. DeHaas and R. Hadfield											
Tensile strength, psi.	86,500	—	—	—	—	—	—	—	—	—	142,000
Yield point, psi.	48,000	—	—	—	—	—	—	—	—	—	96,400
Elongation in 2 in., %	36.0	—	—	—	—	—	—	—	—	—	38.5
Reduction of area, %	74.5	—	—	—	—	—	—	—	—	—	61.0
Brinell hardness	145	—	—	—	—	—	—	—	—	—	—
Experimenters: E. W. Colbeck and W. E. Mac Gillivray											
Tensile strength, psi.	70,700	—	77,500	—	80,000	—	—	85,400	91,500	110,300	—
Proof stress, psi.	20,900	—	25,400	—	24,900	—	—	27,000	28,600	29,600	—
Elongation in 2 in., %	40.6	—	47.5	—	47.3	—	—	40.2	40.6	51	—
Reduction of area, %	75.0	—	77	—	76	—	—	74	74	72	—
Experimenter: H. W. Russell											
Tensile strength, psi.	93,310	—	—	—	102,900	—	—	—	—	—	—
Elongation in 2 in., %	33	—	—	—	37.5	—	—	—	—	—	—
Reduction of area, %	71.7	—	—	—	71.4	—	—	—	—	—	—
Brinell hardness	208	203	—	218	218	222	227	—	—	—	—

Probably too great reliance should not be placed upon the *absolute* values of the low temperature proof stress and yield point, because of the experimental difficulties involved, but the upward trend with decreasing temperature is unmistakable. (Colbeck and Mac Gillivray tested an annealed nickel-copper alloy of the following analysis: Ni 69.58%, Cu 28.86%, Mn 0.28%. Their report can be found in *Transactions* of the Institution of Chemical Engineers for 1933, vol. 11, p. 107.)

Finally, H. W. Russell tested cold drawn Monel down to −103° F. (See A.S.T.M.—A.S.M.E. Symposium on Effect of Temperature on the Properties of Metals, 1931, p. 486.) His data show the hardness to increase steadily but less rapidly than the tensile strength as the temperature decreases. Metal tested had the following composition: 0.08% C, 0.99% Mn, 0.01% Si, 1.78% Fe, 28.85% Cu, 67.87% Ni.

All the data are given in the large table at top of this page.

Modulus of Elasticity

G. H. Keulegan and M. R. Houseman, working at the National Bureau of Standards, have recently determined the temperature coefficients of the moduli of elasticity of Monel in tension and in torsion over the range + 122° F. to −58° F. (See U. S. Bureau of Standards' *Journal of Research*, 1933, p. 289.) These coefficients can be used in conjunction with published values of the moduli to calculate either modulus at any temperature within this range. The temperature coefficient n of the modulus in tension may be defined in either of two ways, each derivable from the other:

$$n = \frac{1}{E}\frac{dE}{dT}$$

$$\text{or, } \log_\varepsilon \frac{E_{T''}}{E_{T'}} = n(T''-T')$$

in which E_T = modulus of elasticity of Monel in tension at the temperature T degrees Fahr., and T'' is higher than T'. Similarly, the temperature coefficient m of the modulus in torsion is defined as

$$m = \frac{1}{G}\frac{dG}{dT}$$

$$\text{or, } \log_\varepsilon \frac{G_{T''}}{G_{T'}} = m(T''-T')$$

Pertinent data are given in the table below.

Since the temperature coefficients are negative the moduli increase slightly as the temperature falls. As the table shows, the temperature

Modulus of Elasticity of Monel

Temper	Modulus		Average Temperature Coefficient 122°F. to -58°F.	Ratio Coeff. at +7... to Coeff. at -5...
	At 75°F.	At -50°F.		
In Tension				
Annealed	25,500,000	25,800,000	-16.4 x 10⁻⁵	1.12
Cold drawn	25,500,000	25,800,000	-16.5 x 10⁻⁵	1.02
In Torsion				
Annealed	9,400,000	9,500,000	-16.7 x 10⁻⁵	1.09
Cold drawn	9,400,000	9,500,000	-17.9 x 10⁻⁵	1.10

coefficients vary slightly with temperature; the coefficients given are the average coefficients over the range 122° F. to —58° F.

Fatigue Resisting Properties

H. W. Russell, in the Symposium above referred to, has determined the fatigue-resisting properties of cold-drawn Monel at room temperature and at —40° F.; these data are listed below:

Load Permitting Life of N Cycles

Temperature	N=40,000,000	N=60,000,000
Room	36,000 psi.	35,700 psi.
-40°F.	38,800 psi.	38,400 psi.

This brings out the important point that the useful alternating stress which can be supported over a long life is greater at —40° F. than at room temperature.

Charpy Impact Resistance

It is well known that many metallic materials having adequate tensile properties cannot be used at low temperatures because of low resistance to shock under these conditions. It therefore seemed desirable to determine whether Monel, which was known to have excellent impact toughness at —40° F., retained this desirable property at much lower temperatures. The data obtained on several grades of the alloy appear below. 45° V-notched specimens were used in all of the present work.

Charpy Impact Tests on Monel

Temperature °F.	Wrought			Cast	
	Annealed	Forged	Cold Drawn	Regular	Grade "H"
Room	216	189	135	74	44
+32	215	—	135	90	52
+10	224	—	140	—	—
-20	212	—	136	—	—
-310	216	184	—	90	47

These data clearly demonstrate that, while the actual level of impact resistance depends upon the temper or grade of metal that is tested, each form or grade of the alloy retains its characteristic level of shock resistance unimpaired to temperatures at least as low as that of boiling liquid air. Microscopical examination suggests that the variations noted above for the cast alloy are due to details of the cast structure, rather than to a real change in impact resistance with low temperature.

The retention of excellent impact resistance at low temperatures shown by the above castings suggests that welds should exhibit the same behavior; Charpy tests and experience with commercially welded Monel plate show that this is, indeed, the case. Thus, butt welded $\frac{3}{8}$-in. plate (weld ground flush) having a tensile strength of 74,900 psi. and 30% elongation in 2 in. across the weld gave (average of 3 specimens) 78 ft-lb. at room temperature and 73 ft-lb. at —310° F. This difference in average values is slightly less than the scatter of values at any one temperature.

The impact resistance of welded Monel is thus of the same order of magnitude as that of other well made Monel castings.

Charpy Impact Tests on Wrought Monel

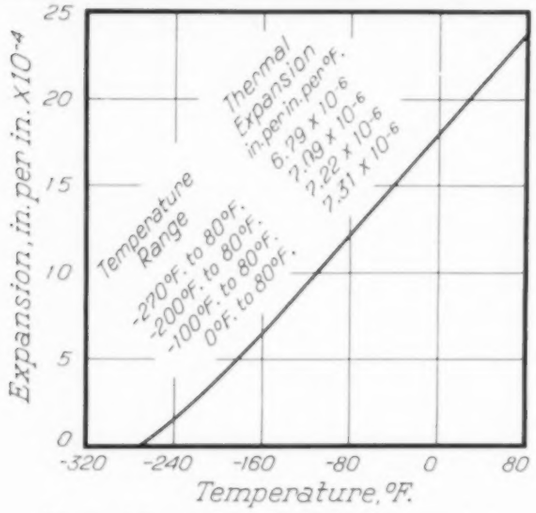
Tests by	Temper	Notch	At Temperature, °F.								
			Room	32	10	-4	-20	-40	-76	-112	-310
Ackerman	Annealed	45°V	216	215	224	—	212	—	—	—	216
Russell	Cold drawn	Keyhole	62	74	—	66	—	62	60	63	—

This retention of room temperature shock resistance at very low temperatures is independent, not only of the grade or temper of the alloy that is chosen, but also of the form of the notch used, as the above data make evident. Tests by the author were made with the V-notch and by Russell with the keyhole notch.

Thermal Expansion

No data on the thermal expansion of Monel as the temperature is raised from that of boiling liquid air to room temperature are available in the literature, in spite of the importance of such information to the designer. An investigation of the thermal expansion behavior of the alloy was therefore made in the research laboratory of International Nickel Co., Inc.

The annealed $1\frac{1}{2}$-in. square forgings which supplied some of the tensile specimens provided the required specimen 4 in. long. The differential dilatometer and general experimental technique were described previously by Howard Scott in *Transactions*, A.S.S.T., 1928, vol. 13, p.



Thermal Expansion for Wrought, Annealed Monel, and Computed Temperature Coefficients for Various Temperature Ranges

829. The instrument we used embodied some modifications designed to improve the positioning of the specimen.

For the present tests the dilatometer was filled with liquid air; after a stable temperature had been reached the dial was read and the liquid air drained out. About three hours was required for the specimen to return to room temperature even though a gentle stream of air was circulated through the chamber containing the specimen as room temperature was approached. The initial and final readings of the dial at room temperature agreed precisely.

The construction of the dilatometer was such that, to obtain the true expansion, the experimental data required correction for the expansion of fused silica over the temperature range studied. Because of the point of reversal in the expansion of silica at about —175° F. (this critical temperature appears to vary from lot to lot) the correction in the present instance was of the same order of magnitude as the experimental error, curves for observed and true expansion coinciding to form the single curve shown. From about —200° F. to room temperature expansion appears to be linear; at lower temperatures expansion was less rapid.

Values for the average coefficient of expansion for annealed, wrought Monel were calculated from the data and are tabulated on the curve sheet at top of the column.

The effect of decreasing temperature upon the mechanical properties of Monel may therefore be summarized as follows:

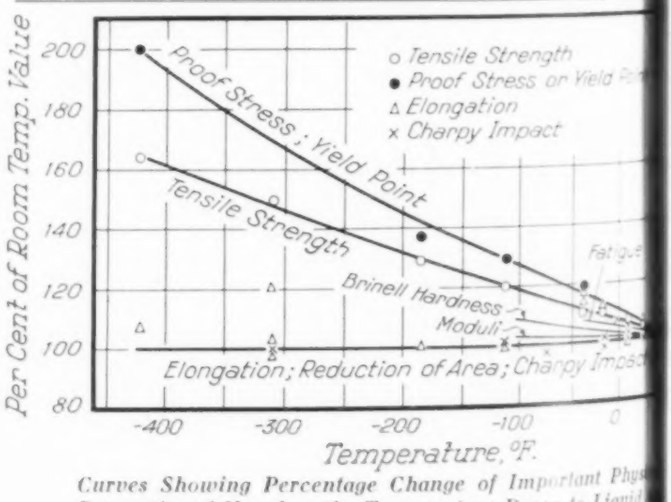
Several properties increase with decreasing temperatures, namely tensile strength, proof stress (and probably also proportional limit and yield strength), tensile modulus, torsional modulus, Brinell hardness and fatigue life for a given load.

At least three important values remain substantially unchanged down to very low temperatures: Elongation and reduction of area in the tensile test, and impact resistance.

Length or volume of course decrease as the temperature drops.

To bring out these generalizations graphically, and to indicate the rate of change of specific properties with temperature, the final figure has been constructed where the values have been plotted in their relationship to those at room temperature.

In some applications such as certain airplane and nautical instruments, it is essential that the metal parts remain non-magnetic to quite low temperatures. Wrought regular Monel is non-magnetic at very slightly elevated temperatures, but becomes increasingly magnetic as the temperature is lowered (although no phase change is involved and the effect is entirely reversible) while the regular cast grade becomes magnetic at about the freezing point of water. However, the Curie point can be lowered by the use of suitable addition elements, and an alloy can be produced which will remain non-magnetic to temperatures at least as low as —112° F., thus affording a material suitable for non-magnetic aircraft equipment and low-power-loss electrical machinery. Cold work does not render such material magnetic at this temperature.



Curves Showing Percentage Change of Important Physical Properties of Monel as the Temperature Drops to Liquid

The author, who is metallurgical supervisor of Bethlehem Steel Co. in Bethlehem, Pa., notes several items of practice that are indispensable for the production of special carbon and alloy steels — notably, selection of raw materials, refining and deoxidation technique, and pit practice. He believes that these items of good practice, rigorously maintained by trained personnel, will produce satisfactorily in tonnage such specialties as ball bearing steels, valve steels and magnet steels, ordinarily made in small heats in the electric furnace.

OPENHEARTH MELTING PRACTICE

BY THOMAS G. FOULKES

THERE ARE TWO openhearth processes for manufacturing steel, namely, the acid and the basic. Each derives its name from the type of bottom used, and this in turn governs the character of the slag. In the basic process, the bases (of which lime is the most prominent), predominate in the slag while the bottom is made of dead-burned magnesite, specially prepared dolomitic limestone, or some other refractory basic material. In the acid process, silica predominates in the slag, while the bottom is made of clean sand containing only a small amount of clay and feldspar. There are a number of combinations in addition to these straightforward processes, four of which may be mentioned as having present importance in America:

1. The common duplex process, wherein molten pig iron from the blast furnace is blown in a bessemer converter thereby removing the greater percentage of carbon, manganese and silicon. The resultant soft steel is then transferred to a basic openhearth furnace (usually of the tilting type) for removing excess phosphorus and sulphur, as well as for refining the metal. This duplex process is generally used in plants having bessemer and openhearth departments near each other and during periods when scrap is scarce and the price is prohibitive, or in districts where scrap is dear and pig iron is cheap.

2. Another duplex process consists of melting the raw materials and removing the phosphorus from the metal in a basic openhearth furnace and then transferring the molten metal to an electric furnace for the removal of additional sulphur and the final refinement and deoxidation.

3. A third duplex process consists of melting the raw materials and removing the desired percentage of phosphorus and sulphur in a basic openhearth furnace and transferring the hot metal to an acid furnace for final deoxidation and refining.

4. In the triplex process molten pig iron is blown in the bessemer converter, thereby removing the greater part of the carbon, manganese and silicon, the hot metal transferred to a basic openhearth furnace for the removal of the desired percentage of phosphorus and a portion of the sulphur, and then placed in an electric furnace for further reduction of sulphur and the final deoxidation and refinement of the steel under special slags.

A brief statement of the main differences between the acid and basic processes may well

be given at this time as a matter of interest to those who are not intimately connected with steel melting processes. In the acid process a reduction of carbon, manganese and silicon is obtained in the bath, but there is no essential reduction in the percentage of phosphorus and sulphur. This necessitates, therefore, the use of low phosphorus and low sulphur raw materials, except in the rare case where high phosphorus and high sulphur steel is being produced.

Basic steel, due to the fact that there is a material reduction of the percentage of phosphorus and sulphur in the metallic bath by oxidation and absorption of the reaction products in the slag, has the advantage of lower priced raw materials.

In manufacturing basic openhearth steel there are possibly five classifications of steel, as far as their application is concerned:

1. Rimmed steel.
2. Semi-killed steel.
3. Fully-killed carbon steel.
4. Special quality alloy steel.
5. Special analyses (not usually an openhearth product).

Since the author's experience has very largely been confined to the special carbon and alloy steels, furnace procedure and pit practice for these steels will be presented in some detail, noting wherein the various other grades of basic and acid steel differ therefrom.

Available Raw Materials

In the discussion of furnace procedure the subject of raw materials and their selection will first be presented.

For use in the manufacture of special carbon or alloy steel in the basic openhearth, pig iron should generally conform to the following specification:

Manganese, 2.00% minimum.
Phosphorus, 0.35% maximum.
Sulphur, as low as possible; it may contain a maximum of 0.06% provided the fuel is low in sulphur and the iron high in manganese.
Silicon, 1.25% maximum.

Manganese is listed at 2.00% minimum to take full advantage of its desulphurizing action in the basic melting process.

The phosphorus and sulphur restrictions assure satisfactory elimination of the surplus of these elements without undue loss of time or undue consumption of fluxes.

With the silicon at 1.25% maximum there is less corrosion of the basic furnace's banks by the acid SiO_2 than if silicon in the pig is considerably above 1.25%. Likewise there is less possibility that the oxidized and rejected phosphorus may leave the slag and re-enter the steel bath, as definite basicity must be maintained in the slag to enable it to retain phosphorus. As an additional reason for specifying 1.25% maximum silicon there is the neutralizing requirement in the basic process which necessitates increased limestone additions with silicon content much in excess of 1.25%.

(In the acid process, silicon in excess of 1.75% in the pig iron is desirable. Phosphorus and sulphur should be under 0.035% each, due, as stated above, to the fact that there is practically no elimination of these elements in the acid process, and due to the fact that some sulphur may even be absorbed from the fuel.)

While it is not necessary to carry a minimum of 2.00% manganese in the iron when making the cheaper grades of basic steel, it is quite generally agreed that it is economical to do so since such steel rolls better, by virtue of the lower sulphur content. (A portion of this element is removed by the surplus manganese.) In melting practice there is also an advantage in the better working of the heat with this minimum manganese content.

While the above specifications for pig iron are highly desirable, *consistent uniformity* of analysis is the most important requirement.

While one of the advantages of the openhearth process is its ability to remelt economically the crop ends and other such scrap made in rolling and finishing, yet obviously no plant properly operated will produce sufficient scrap to satisfy its own melting department. It is necessary, therefore, to procure a substantial portion of the scrap required from outside sources, and a large American industry has been built up to collect and supply this need.

In the purchase or allocation of scrap for special steels, selection should be made on the basis of analysis and physical condition. Where the analysis is not clearly known, sampling for that purpose should be done by an experienced inspector. The presence or absence of certain elements in the composition will determine its allocation; for example, steel scrap containing appreciable nickel would be desirable when making a heat of nickel steel but highly undesirable when a low maximum nickel content is specified. Scrap for the acid openhearth must be low in phosphorus and sulphur, and the

High Grade Pig Iron, Uniform in Composition, Is an Essential for Quality Steel. Photos by Van Fisher

maximum allowable is dependent on the percentage desired or permitted in the finished steel — generally such scrap should not be in excess of 0.035% for either of these impurities.

The above comments on raw materials emphasize the importance of their proper selection as a definite aid in the production of steel of good quality. The production of good quality steel without the aid of careful selection of raw materials, while of course possible within chemical limitations, is generally uneconomical.

Limestone is a raw material having important functions in basic operations. It is highly desirable that it be uniform in composition, low in MgO and SiO_2, high in CaO. The exact restrictions on analysis of the limestone depend on commercial considerations.

Selection of fuel depends on cost and availability. Those in use are gas, oil or tar. High calorific value and low sulphur content are required. For example, in making some of the special analyses in the acid openhearth, with oil as the fuel, it is necessary that it have an exceptionally low sulphur content. When making high sulphur steel such as screw stock this is obviously unnecessary. Even on the cheaper grades of basic openhearth steel where oil containing a maximum of 0.75% sulphur can be obtained at not too great a premium, it is entirely possible that the better rolling of the steel may make the use of such good oil desirable.

As in the other raw materials, uniformly high quality is desired in the ferro-alloys employed. Reliable manufacturers produce ferro-alloys of uniform composition and quality, and these materials should be purchased from such manufacturers.

Notes on Melting and Refining

In charging the basic furnace approximately 10% of limestone is included on alloy and special carbon heats to provide the CaO for the required basic slag. A slag sufficiently basic in reaction absorbs phosphorus oxide and prevents its subsequent reversion to the steel bath. The lime likewise combines with other liquid products of deoxidation and holds them in the slag, thus cleansing the steel bath of such products. While this extra amount of limestone put into the furnace increases the time required for melting and thus decreases the furnace life, its use is warranted in the production of high quality steels.

Slag samples are drawn at intervals during the first three hours under heat, quick chemical analyses made and their viscosity determined by simple test. Corrections may be made to the ratio of bases and acid components, depending on the trend of the test results, so that the slag will be in the proper condition during the refining period with no delay and with minimum cost of additions such as ore, lime or spar.

Final deoxidation of the steel bath is of great importance in the production of special steels. The actual practice utilized in this stage is the one found to deoxidize the bath most satisfactorily, and the choice of deoxidizing alloy such that the products of deoxidation will possess ready fusibility and agglomerate easily into sizable droplets. It is, of course, necessary that the deoxidation products rise to the slag and be retained by it in order that the steel may be cleansed of these impurities. The use of 14% ferrosilicon, silicon-spiegel or spiegeleisen is usual, either alone or in combinations. In one method the bath is permitted to come back to a boil after the first deoxidizing alloys have been added. Following this boil a second addition of a similar deoxidizing alloy is made to hold the carbon constant and further deoxidize the steel. Another method of final deoxidation con-

sists of making one large addition of silicon-spiegel to the bath, followed by whatever alloy additions are necessary, without allowing the metal to come back to a boil.

After final deoxidation, the bath showing proper carbon content, such additions as ferrochromium and ferromanganese are made and the heat tapped.

In both the acid and basic processes the alloying elements nickel and molybdenum are added in the furnace. Nickel is added as metal and molybdenum as ferromolybdenum or as a salt of molybdenum. These additions may be made at the time of charging the furnace or at any time during the melting or refining operations as there is practically no loss from oxidation. The additions are usually made early in the heat program.

Ferrochromium and ferromanganese are added in either the basic or acid furnace late in the heat program, the ferrochromium approximately 20 min. and the ferromanganese approximately 10 min. before tapping. Earlier addition would result in excessive oxidation losses. These alloys are added in the furnace rather than in the ladle to obtain more uniform solution and dispersion, although ferromanganese may be added in the ladle when making less important basic openhearth grades.

In the acid process ferrosilicon is most frequently added in the furnace, since oxidation losses are not so great as in the basic furnace. In the latter, however, ferrosilicon is added in the ladle, which gives satisfactory uniformity in the normal silicon specifications. In high silicon basic steels, re-ladling is advisable to secure the desired uniformity. If the ferrosilicon were added in the basic furnace, instead of the ladle, the furnace banks would be badly corroded and there would also be greater oxidation losses, for silicon is readily oxidized. The ratio of base to acid in the slag must be maintained insofar as possible, as its ability to absorb and retain phosphorus determines the phosphorus

Action on the Furnace Floor! The tap hole has just been opened and the crew pulls the bar back out with a will

content of the steel. This ability depends in turn on maintaining a satisfactory minimum ratio of base to acid in the slag. By adding the ferrosilicon in the ladle, it enters the molten steel (drawn off below the slag) without slag interference.

Likewise, ferrovanadium is added in the ladle. Vanadium oxidizes readily and additions to the furnace would result in excessive losses. Ladle additions of ferrovanadium are also common in the acid process for the same reason, although it may be added in the furnace, as the losses there are considerably less than in the basic furnace.

In both processes the percentage recovery of the alloys, as well as the quality of the steel produced, is dependent on the analysis of slag, particularly the percentage of FeO remaining in solution at the time. If the FeO in the slag is too high, the iron oxide in the steel will be correspondingly high, percentage recovery of the alloys will be low, and the difficulty of completely deoxidizing the heat is greatly increased. On the other hand, if the FeO in the slag is too low there is danger (in the basic process) of phosphorus reverting to the bath. The old saying that "to make good steel you must make good slag" is still true.

Pit Practice Important

Well controlled furnace practice warrants equally well controlled pit practice. Steel of excellent quality may be tapped from the furnace only to be found inferior in later metallurgical inspection due to improper pit practice. Cleanliness of stools and molds into which the steel is poured is paramount. Protective coatings on the mold walls are necessary for the best results. Steel pouring temperature and temperature of the mold, as well as mold design, are important controllable factors in the production of quality steel.

As the metal leaves the furnace, it is general practice in alloy and special carbon steel manufacture to determine its temperature by an optical pyrometer, and to hold it in the ladle a definite time before "opening up" in order to teem at the temperature which has been found, by experience, to be proper for that particular grade. It is the author's belief that attention to this will pay for itself in increased life of molds and stools as well as in improved surface of the rolled product. In order to be sure that the holding time has resulted in the proper pouring temperature, additional temperature readings are taken several times during teeming of the metal into the molds.

Big-end-up molds, with ratio of length to diameter and contours designed in accordance with plant experience and current engineering practice, are used for alloy and special carbon steel ingots. Refractory hot tops are placed on the molds so as to retain molten steel in such a sink head while the body of the ingot beneath is solidifying, and to feed contraction voids which would otherwise occur in killed steel. The protective coating for mold walls, referred to above, is usually tar, graphite, or aluminum paint. Without such coating there would be a chemical reaction between scale on the walls and the molten steel. The coating also prevents splashes of molten steel from adhering to the walls of the mold. The rate of pouring is also of importance, and is decided by plant experience for the various grades of steel produced. In fact, *all* factors in pit practice are given close attention in the production of quality steels.

Many manufacturers of the cheaper grades of killed steel are gradually adopting big-end-up molds equipped with hot tops, and more and more of the manufacturers of semi-killed steel are using some type of mold coating.

Grain size control is a much discussed subject of prime interest in connection with open-hearth melting practice. It requires tonnage production of steel, which will have a certain specified size of micrograin or fracture grain, either as received or after definite heat treatment, as the case may be.

Control of Grain Size

In general a "fine grained steel" is one wherein the austenitic grain grows very reluctantly as the time and temperature increases above the critical — especially during a normal carburizing operation. One school of thought ascribes this retardation of austenitic grain growth to a fine dispersion of submicroscopic non-metallic inclusions, such as oxides. Others ascribe this retardation to the inherent properties of a solid solution of the deoxidizing element or elements in the steel. The published evidence is not conclusive to either view. It is believed probable that a proper dispersion of submicroscopic particles *together* with a controlled excess of the deoxidizing element in solid solution is necessary to obtain such a fine grained steel.

Grain size control or regulation does not mean the production of *fine* grained steel only. It is equally important to produce, when the requirements warrant, uniformly *coarse* grained steels. This is also grain size control. As is well known, there are machining requirements definitely indicating the desirability of coarse grained steels.

Some of the existing limitations of hardenability and analysis, specified by purchasers of steel products, compel the producer to furnish coarse grained steels, which frequently lack the toughness and other requirements of the part to be manufactured. However, it is recognized that in many instances the specified limitations as to analysis could be removed, making possible the application of a fine grained steel meeting the hardenability requirements. This would furnish the purchaser the other general advantages of the fine grained steels, such as increased toughness, reduced distortion and reduced tendency to such troubles as quenching cracks and grinding cracks.

Aluminum is the most common deoxidizing element used for controlling the grain size (obtaining the desired degree of retardation of austenitic grain growth). In general coarse grained steel may be obtained by a slight use of aluminum (or by its complete omission) while fine grained steel may be obtained by the use of considerably more aluminum. It is also recognized that other deoxidizing elements may be substituted for aluminum in part.

While this general statement makes the control of grain size sound much like an extremely simple operation, capable of systematic arrangement in something like the multiplication table, it is in fact far more complicated. There are a number of factors that affect the resulting grain size obtained by a definite addition of aluminum, when such grain size is determined by any of the prevalent methods such as McQuaid-Ehn carburizing test, the Shepherd fracture scale, or gradient quenching as recommended by Bain and his associates. Chief among these factors in openhearth practice are *(a)* degree of oxidation of the molten steel at the time the addition is made, *(b)* time and temperature effect on the loss in aluminum from the time of addition to solidification of steel. There are also other factors subsequent to solidification affecting the grain size, chief among which are *(a)* prior structure, *(b)* hot working practice, *(c)* cold work, and *(d)* testing technique — to mention but a few.

Special Analyses in Tonnage

Earlier in this paper the author referred to special analyses which are not usually considered as an openhearth product. Several such analyses are *(a)* bearing steels, *(b)* intermediate alloy steels for high temperature application, *(c)* magnet steels, *(d)* automotive valve steels.

Until recently, such alloy steels have been considered as electric furnace products only, no doubt due to the following reasons:

1. Cleanliness of material required.
2. Phosphorus and sulphur limits.
3. High melting point of these steels.
4. Small size of orders.

Discussing these various reasons:

1. Owing to the reducing character or type of slag that can be maintained in the electric furnace it is possible to deoxidize the bath more easily. Yet it has been demonstrated repeatedly that with specially trained personnel and with proper slag control and proper use of deoxidizers, steel of these special analyses can be made in both the acid and basic openhearth furnaces which compares favorably with the average electric furnace product.

2. It is not possible to obtain as low a content of phosphorus and sulphur in steels made by the openhearth processes as can be obtained in electric furnace steel, yet these elements can be reduced sufficiently to satisfy most requirements if made in the acid openhearth of specially selected raw materials. With special selection of raw materials, and special furnace practice, it is possible to obtain steel by the basic openhearth process, low enough in phosphorus and sulphur not only to produce a satisfactory product but which also approaches the composition limits obtained in regular electric furnace practice.

3. Sufficient temperature can be obtained in the openhearth furnace to properly melt and refine the above mentioned special analyses.

4. It is possible, in the openhearth process, to produce these grades in larger heat lots, resulting in *(a)* less testing, *(b)* less variation in analysis and other conditions which are characteristic of a given heat of steel, and *(c)* lower manufacturing cost and selling price.

In view of the above advantages, the author believes that the manufacture of these alloy steels in the openhearth furnace is a distinct contribution to the art, because it should result in a wider application of these analyses to common articles of commerce.

ELECTRIC STEEL

METAL PROGRESS
NOVEMBER 1936

The Editor desires to acknowledge
the many courtesies extended by
The Timken Steel & Tube Co.
in the photographing of this story
at the plant in Canton, Ohio

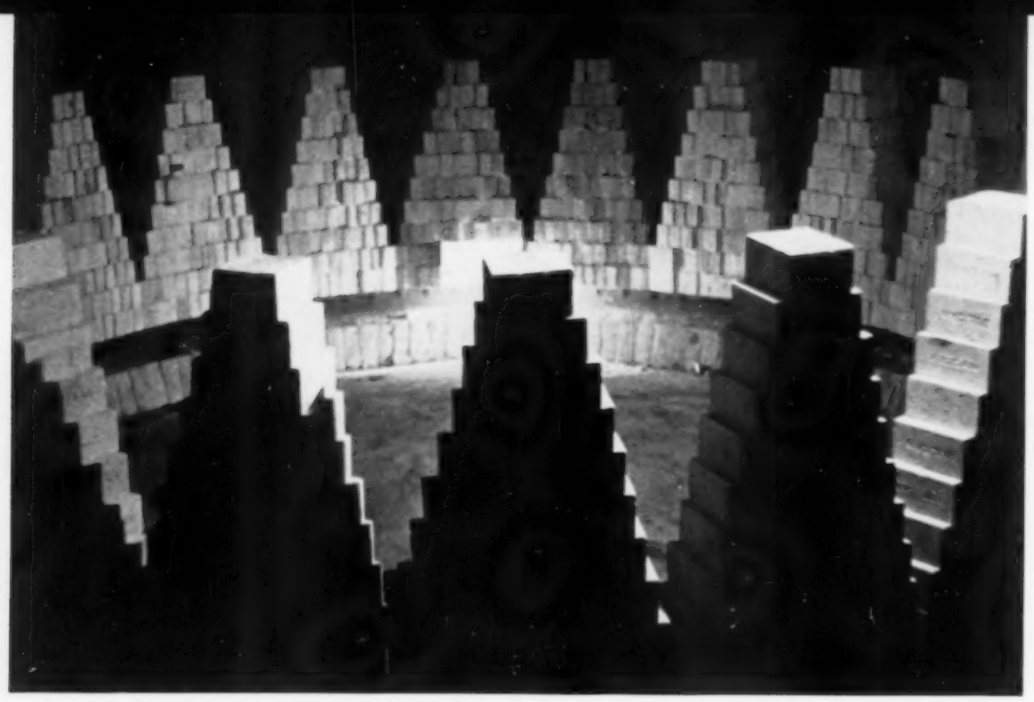
Photographed by Van Fisher

BLINDING HEAT! An inferno too hot for flame! Tophet! The focus of the nethermost pit, tamed to the will of man! — A layman's conception not far wrong, for one great advantage of the electric furnace is its stark, roaring, prodigious heat.

Steel, the metal, is as ancient as civilization, and those there are who hold that the old Damascus blades have yet to be matched. Nor will the Sheffield artisan relinquish his belief that crucible steel, melted from clean iron, is the masterpiece.

But the onrushing mechanical age needed steel, steel, more steel, cheap steel, steel soft and tough. Bessemer's steel in such tremendous tonnage that in less than a half-century the flaming converter had burned out the suitable ores. Not to be thwarted, engineers built openhearth furnaces to refine the mountainous deposits of less pure ones.

Even then perfection was not reached, nor will it ever. One step nearer is the electric furnace, where, instead of pumping air through the iron to purify it, or bathing it with incandescent flame, thus contaminating it insidiously as we burn out its dross, we bombard it with electrons, infinitesimal particles of energy, very atom stuff, and excite it to swift reaction.



A brickmason, orderly soul, likes to stack up the brick before building a domed furnace - top Many are needed for a circle down near the haunches, few near the crown.

The big furnace awaits its charge. A heat of molten metal has been tapped, the bottom and banks repaired — a cycle finished. Electrodes, drawn up full height, clear the hearth so the charge of scrap and flux can be piled in through the doors.

Of the several raw materials needed for alloy steel, two are metallic. First is carefully selected and graded scrap, heavy billet croppings and light trimmings of sheet and plate — for the main function of the electric furnace is to take commoner steel, melt it under cleansing slag, clear it of dissolved and combined gases, melt and mix in the alloys. These ferro-alloys, themselves children of arc furnaces, are in glittering iridescent lumps, impossible to picture in printer's ink.

Metal Progress; Page 72

Two other requisites for electric steel are Men and Heat. No robots for melters and helpers; they must be wise to the ways of their fiery pet, yet always quick to think and act when hell breaks loose. Robots are for the heat control, pulling up and dropping down the electrodes in an incessant oriental dance, drawing out the flaming arc, safely within the capacity of supply and transformers . . . . Men, conquering the concentrated energy of five thousand horses!

Almost any furnace in commercial production needs a mechanical charger. It's impossible work to throw tons of metal into a furnace, too slow and wasteful of operating time and heat, as well as hard on door jambs and lining brick . . . Once the charge of flux and metal is in, the doors are closed, the heat turned on and melting starts. The pool of gently boiling metal loses its impurities gradually to the slag, floating on top; carbon also changes slowly.

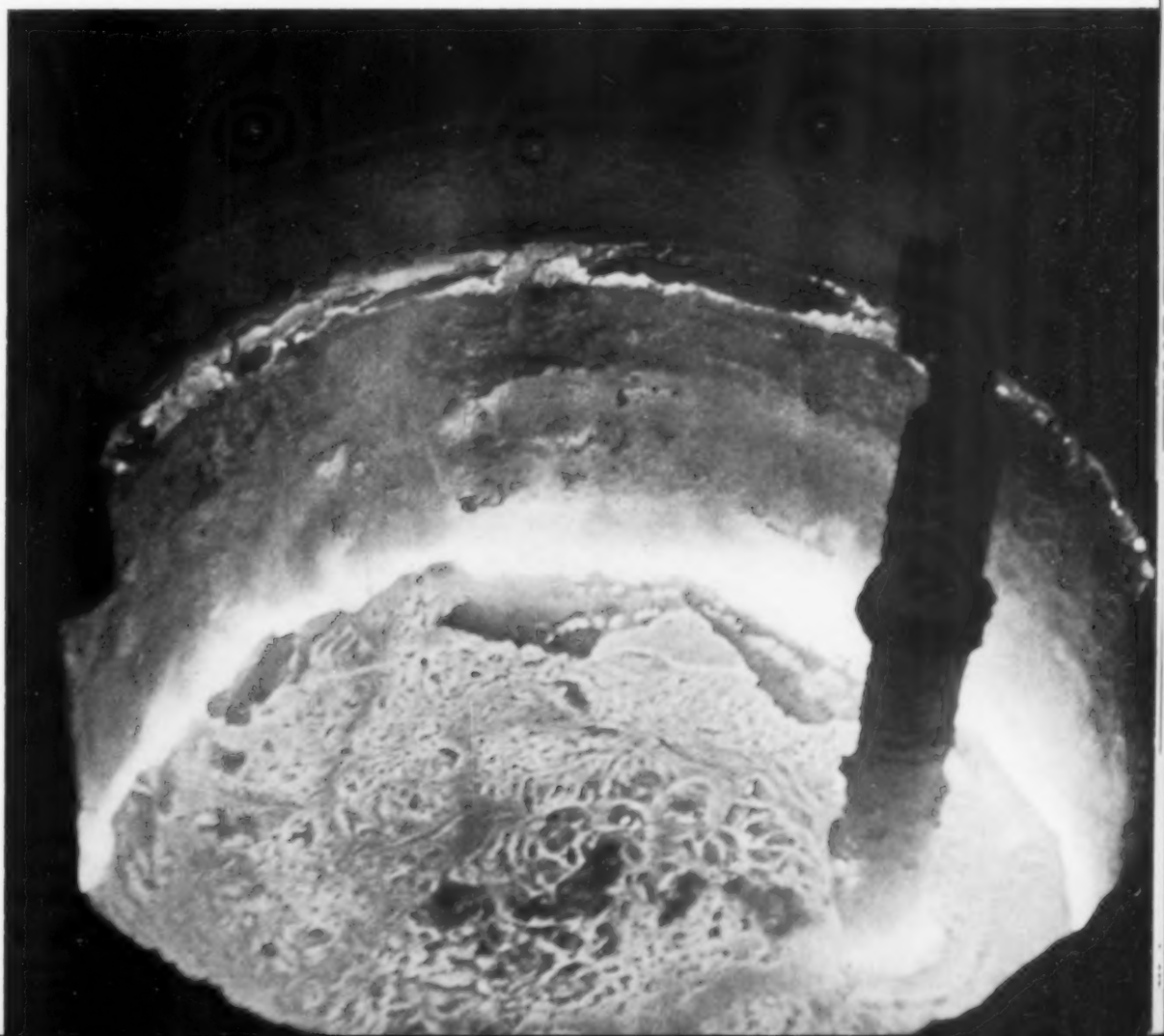
To gage the course of these reactions, the furnace man takes small samples for chemical analysis, and he judges the condition of the metal by its fracture and the slag by its color and texture. Changes in metal and slag are mutual and inter-dependent; they tell the same story in entirely different languages, a polyglot for the chemist to translate and the melter to read.

When the first slag has absorbed phosphorus, silicon and other impurities to its limit, it is skimmed (hot, careful work, this) leaving the metal clean for a second slag, mostly lime with a little crushed carbon and spar. Only for electric steel is this double refining; only under the heat of the arc can such a second slag be melted and calcium carbide formed, a substance avid for the sulphur and oxygen remaining in the metal.

Action: A shovel of spar gets to the exact spot.

Metal Progress; November, 1936; Page 76

Slag right, carbon right, alloys in, final deoxidizers added, temperature right—then the tap hole is opened, the furnace tilted, and fine steel flows out into the waiting ladle below.



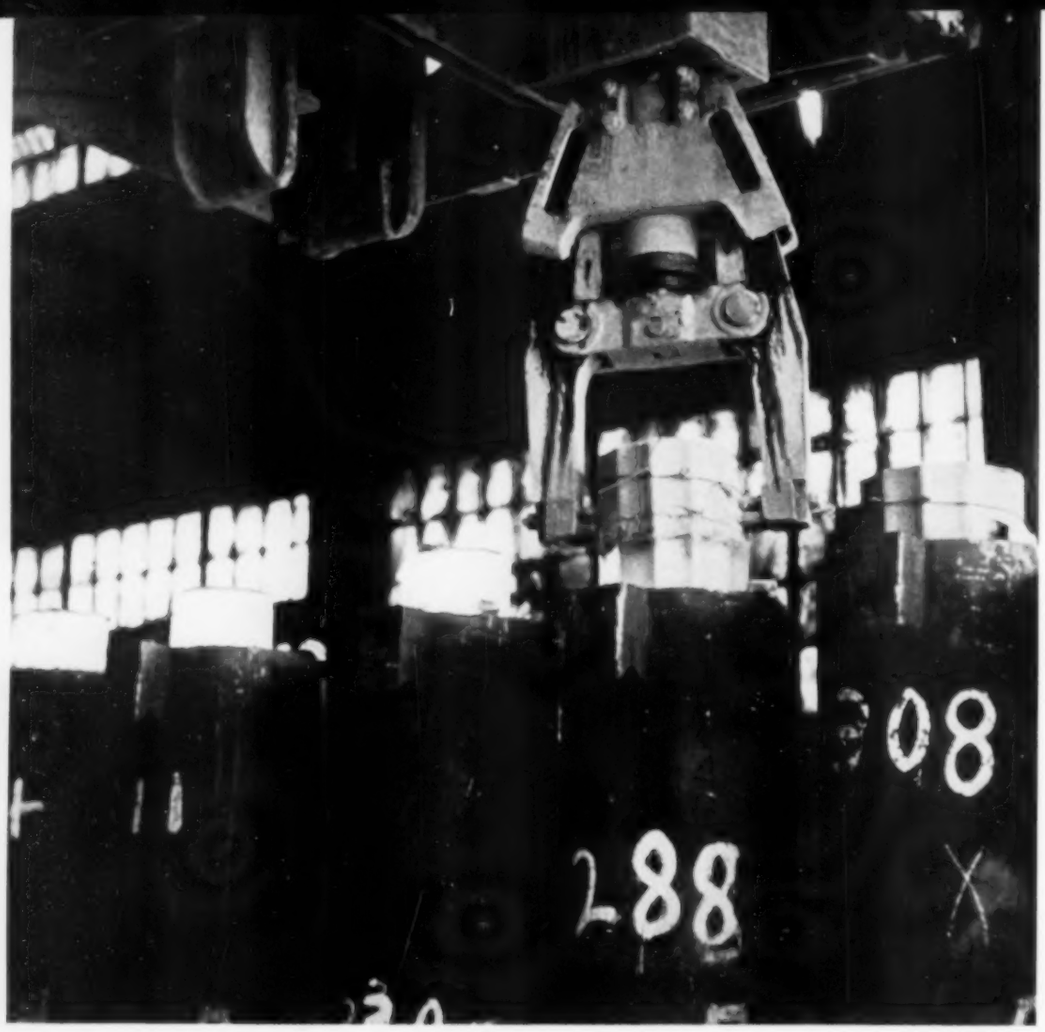
Enough superheat is in the metal so it can cool quietly in the ladle for a time, allowing fine inclusions to rise to the slaggy scum floating on top.

Pit practice — all those operations concerned with changing liquid steel into a solid ingot — is of prime importance. Mold design itself has been a life study. Molds must be clean; a powerful vacuum suction attends to this. Finally a tarry compound is sprayed into the mold, lining the walls and improving the outer surface of the eventual ingot.

In the ladle-bottom is a fireclay nozzle, closed by a plug which the foreman can raise and lower at will, thus controlling the stream of metal which spurts through. First, however, he makes sure that the nozzle is accurately centered over the mold. Nearby an observer with optical pyrometer checks a white-hot temperature

Once at the beginning, once in the middle, and once near the end — three times at least ladle samples are taken for final chemical analysis and an accurate check against orders.

uality steel is cast into ingot molds th hot tops, which may simply be fractory prolongs, or be metal cast- s lined with insulating brick. These tain a pool of molten metal, long after bulk of the ingot has solidified, dy to feed any contraction cavity at otherwise would appear below. workman covers the hot metal th some fine sand to check radiation.



After the ingot has completely solidified, and further cooled to a temperature judged best for its contour and composition, it is stripped from its mold. Overhead a crane carries a vertical arm and two massive fingers which pick off first the hot top, then loosen the ingot from the mold ready to enter the glowing soaking pit . . . Here our story ends, the story of electric furnace steel. Subsequent chapters have to do with the rolling mill, of which the soaking pit is the introduction, for here the ingot's temperature is slowly equalized, surface to center, finally reaching a condition ready for the blooming mill, the first step in converting it into a usable shape.

Constant advance in the production of high quality alloy steels brings many problems of operating technique, not the least of which have to do with the refractories with which the molten metal comes in contact. Mr. Callinan, refractories engineer in the research department of Timken Steel and Tube Co., Canton, Ohio, now outlines some of the requirements and recent findings of studies made at that place and in the plants of cooperating firebrick makers, in a paper originally presented at a meeting of the Ohio Ceramic Industries Association

REFRACTORIES IN THE POURING PIT

BY EDWARD E. CALLINAN

MANY FACTORS affecting pouring and teeming conditions in alloy steel production are important, and this has drawn attention to the refractories used in these operations. Much may be done to maintain the high quality in molten steel by the proper selection and use of ladle linings, stoppers and hot tops. Non-metallic inclusions in the steel, originating from the refractories in the furnace, spout, ladle, or mold will cause low cutter life and high tooling cost in the production of machined parts. Deeper seated inclusions will also cause lines of weakness or concentrations of stress in the product which may result in failure in service. As a result, alloy steel producers are studying this problem, and with the cooperation of the refractories manufacturers, have gone far in overcoming its worst phases. They are more concerned with the quality of their steel as affected by refractories than they are with refractory service life and cost per ton.

Molten slag and metal attack the refractories exposed to them chemically (corrosion) and by mechanical action (erosion). The materials so exposed must therefore have not only ample heat resistance but also the correct physical and chemical properties, even when the latter may involve some sacrifice of the refractory value.

Probably the greatest action occurs in the ladle, because of the violent impact when the metal stream strikes the bottom, the turbulent currents and splashing as the ladle fills, and the sudden heat shock when hot metal rises in the relatively cold container. Ladle design has a very definite effect on the life and utility of the ladle refractories, and any change in design must be considered in the light of the effects it will have on the slag and steel and on general teeming conditions.

Attack of the refractory ladle lining is influenced by the chemical properties of the slag and steel, their temperatures, and the time the steel remains in the ladle. Much of this abraded and corroded refractory material undoubtedly occurs at the nozzle. Here there is a combination of high velocity of liquid steel, a high pressure generated by the ferro-static head, and a large contact area per volume of steel. Design of the nozzle and stopper plays an important part here, since it helps to control velocity, temperature and pressure.

In teeming, the mold hot top and plug may

be subjected to severe impact and sudden temperature change. Solidification of the metal occurs rather rapidly at the bottom stool and along the sides of the metal mold because of the high heat conductivity, thus giving included particles little time to rise out of the metal.

Ladle Brick and Mortar

Most present-day ladle brick have a pyrometric cone equivalent of cone 23 (2840° F.). Generally, they are made of rather siliceous clays, a typical chemical analysis of a ladle brick showing 66% silica, 25% alumina, 4.5% iron and titanium oxides, and 0.4% lime, the remainder consisting mainly of magnesium, sodium and potassium oxides. Maximum firing temperature is about cone 5 (2200° F.), the firing schedule being closely controlled and progressing at a very slow rate, this being of more than usual importance for a satisfactory product. The fired brick are quite hard and dense, having a water absorption of 7 to 9%; however, they do not appear to be highly vitrified. These properties are essential to resist penetration and fluxing by slag and steel.

Theoretically a 65% silica fireclay brick is entirely unsuited for basic steel ladles; a basic brick would be better. However, magnesite brick and basic or neutral rammed-in linings have not been fully successful, since their higher heat conductivity abstracts so much heat from the melt that a skull tends to form rapidly in the ladle. They also spall, while the author has never observed any signs of spalling of a regular ladle brick which has been entirely covered with slag or steel. The fireclay ladle brick seems to slough off as a thin layer during each pour, the resulting surface being smooth and evenly eroded.

A regular, first quality firebrick does not give as satisfactory service as does the more siliceous ladle brick. It seems to wear more rapidly, probably because of its higher porosity and lesser degree of vitrification, and tends to "peel off," the slag adhering to it and pulling off a thin layer of the uncontaminated brick. Breaks occur around the large grains of grog. This may be explained by the fact that frequently the grog has been calcined to a temperature only sufficient to eliminate shrinkage at the firing temperature. On exceeding this temperature under actual service conditions, further shrinkage of the grog occurs and it pulls away from the clay. This produces a zone of weakness and allows the turbulent metal currents to wash away the grains, thus creating potential inclusions.

Good practice in the lining of ladles calls for uniform sized brick, medium thin, tight joints and proper use of such shapes as wedges and arches. Some operators have noted that the use of high temperature cement rather than ordinary ground fireclay for mortar has increased the life of the lining as much as 10%, and also reduced the inclusion count of the steel.

Nozzle and Stopper Shapes

Pyrometric cone equivalents of clay nozzles may range from cone 18 (2715° F.) to cone 30 (3000° F.), cone 18 nozzle having a softening point around 2400° F. Almost all nozzles appear to consist of clay and a rather small percentage of medium fine grog. They have a water absorption of about 7%. Cursory microscopic examination does not show evidence of high vitrification but does disclose rather considerable amounts of free quartz, well distributed in the clay substance. Hard-burned nozzles and sleeves are rejected by most steel plants since they have a greater tendency to crack and spall. Care must be exercised during drying and firing treatments that no warpage or deformation occurs, since an imperfectly shaped nozzle may directly affect the quality of the steel which passes through it.

As all steel makers know, the successful teeming of a heat depends on the nozzle, which has two main functions, first to be an outlet for and to control the character and velocity of the stream of metal, and second to act as a seat for the stopper head in shutting off the flow of metal when a mold is filled.

If a clay-graphite stopper head has been used, examination after teeming will show that it has retained its original shape almost perfectly, while the nozzle will disclose that the stopper head has been pushing into it and that some of it has been washed out by the steel. The hot nozzle itself is in a pyro-plastic condition and as long as it does not deform or flow too much as a result of the temperature or the fluxing action taking place, this plastic condition is really desired in order that the stopper will seat and shut off the metal stream cleanly. A rather delicate balance must be maintained between softening by temperature and fluxing action of metal in both the stopper and nozzle. If the steel is either too hot or too cold, sticking may result.

especially if the stopper-head is of clay. Best results are obtained when the two pieces do not have the same softening point.

Sometimes only a partial shut-off is obtained and the steel slowly dribbles through. This may be due to faulty design of the nozzle, stopper, or the nozzle well, cracking of the nozzle, excessive erosion, insufficient plastic deformation of the nozzle to allow the head to re-form the seat, or formation of a skull in the nozzle well. It is essential that there be good initial contact between the head and nozzle. Both pieces must be closely inspected before and after being set in the ladle. In some cases faulty nozzles may be ground by a specially shaped cutting wheel so as to make a perfect seating area. If the interior is softer than the surface skin this grinding may expose soft material and produce teeming difficulties, making it essential that the nozzle be fired correctly.

The nozzle must be so set in the ladle that the hole will be absolutely vertical. If not, the stream will hit the side of the mold before it reaches the bottom. Again, the bottom surface of the nozzle tip must be exactly perpendicular to the nozzle hole, for otherwise the stream will be thrown to one side or may spray. Such conditions will decrease the life of the molds and result in faulty ingot surfaces, for hot steel sprayed on the mold sides and freezing before the metal in the mold can reach it will form scabs on the ingot surface, thereby increasing chipping costs and sometimes causing rolling difficulties. The original diameter of the nozzle hole and its variation in size as it is eroded by the steel is of considerable importance for the same reasons.

Graphite nozzles with clay stopper heads and magnesite nozzles have not been used to any large extent. Magnesite, due to its higher heat conductivity, may develop a skull in the nozzle well. It also exhibits a tendency to build up and decrease the size of the opening.

Sleeves for Stopper Rod

Pyrometric cone equivalents for sleeves will vary from cone 26 (2895° F.) to cone 29 (2975° F.). Usually they are more refractory than nozzles and have a higher water absorption value, from 9 to 12%. This may be due to the fact that they appear to contain a larger percentage of coarse grains.

Since the stopper rod acts as an arm to control the stopper head and also as a heat conductor in removing heat from the stopper head, metal bolt, and pin assembly parts, the sleeve bricks protect the rod from attack by slag and steel and also insulate it sufficiently to allow heat to flow up through it from the stopper. As the sleeves become thinner, this important cooling effect is decreased.

Sleeves are jointed with a high fusion, low shrinkage, flint base clay and must be handled carefully to avoid cracking at the joints. Quite often an air-setting chrome cement is used to bond the bottom sleeve to the stopper head, and in some cases air-setting fireclay cement is used in the sleeve joints. If this is done, the cement must not contact the rod and bond the sleeve to it, because the sleeves expand approximately $\frac{1}{16}$ to $\frac{1}{8}$ in. per ft. and adherence to the rod may cause the joints to break.

Hot Tops—Required qualities include: (1) Maximum resistance to cracking from heat shock, (2) resistance to attack by steel, (3) accurate size and proper design, (4) insulating value, (5) freedom from materials which will produce a gas when the hot top is heated by the metal, (6) light weight for easy handling.

Clay hot tops are usually made by extrud-

ing horizontally from an auger machine, or in presses as in the manufacture of sewer pipe. After cutting to length they are dried and fired to about 2000° F. After firing they usually have a water absorption value of 8 to 11% and a pyrometric cone equivalent ranging from cone 18 (2715° F.) to cone 28 (2950° F.). As the bottom edge of the hot top is partially immersed in the steel the refractoriness, fluxing resistance, and surface condition are quite important. It is desirable that this bottom edge be smooth so that a dense, smooth, minimum surface area will be exposed to the steel.

A hot top for a 19-in. round mold will weigh approximately 110 lb. Recently, lighter tops, weighing 70 to 75 lb., have been made by introducing coal, sawdust, or other materials which will be burned out during the firing operation. These lighter tops are cheaper to handle and control better the pipe in the ingot, since they are better heat insulators and have lower heat capacity. Such tops will stick to the steel if open pores are present on the inner surface.

Tapered cast iron tops lined with firebrick or insulating firebrick are now being rather widely used. The taper reduces the amount of steel in the top from 10 to 15%, and the lining, being a better insulator, is more efficient in reducing pipe. The brick lining is coated with a special slurry (graphite base refractory) to prevent penetration of the steel and allow them to be removed from the ingot more easily. These tops are performing satisfactorily both from the standpoint of steel quality and of costs.

Clay Plugs

Clay plugs have a pyrometric cone equivalent ranging from cone 23 (2840° F.) to cone 28 (2950° F.), and absorption varying from 7 to 10%. They are made of a clay grog mixture and hard fired. However, they must not be too highly vitrified or a shell of material will break off when the metal stream strikes them. They must be accurately sized so as to make a good seal at the base of the mold. Surfaces must be smooth with no rough edges, fins, or loose sand, and the firing or forming must not develop a skin or laminations which will spall off. When fireclay inclusions are found in steel quite often they may be concentrated in metal from the lower end of the ingot. Hence it is believed that faulty plugs are one of the chief sources of inclusions.

Various schemes have been tried to render plugs more serviceable. The upper edge has been rounded to reduce chipping. The top has been dished out to reduce the erosion by the metal stream. They also have been capped with sheet metal, either by forming the sheet over the plug or by simply placing a piece of sheet steel over the plug. Both of these have disadvantages, for the steel cap prevents a good tight seal, while the loose plate will be washed away as soon as the stream hits it. Experiments have been made with plugs having a metal plate *fastened* to them, which eliminates the two undesirable features previously described, and seems to offer very satisfactory results, as the plate remains in place and the plug is not fluxed or spalled.

In this, as in other features of pit refractories, much work still remains to be done in solving the problem of non-metallic inclusions in steel. This is going forward in the laboratories of steel plants and refractories manufacturers and important advances are being made. As remarked at the outset, steel producers are constantly seeking means of improving the quality of their product and particular attention is being centered on the broad subject of refractories—furnace linings as well as pouring pit materials.

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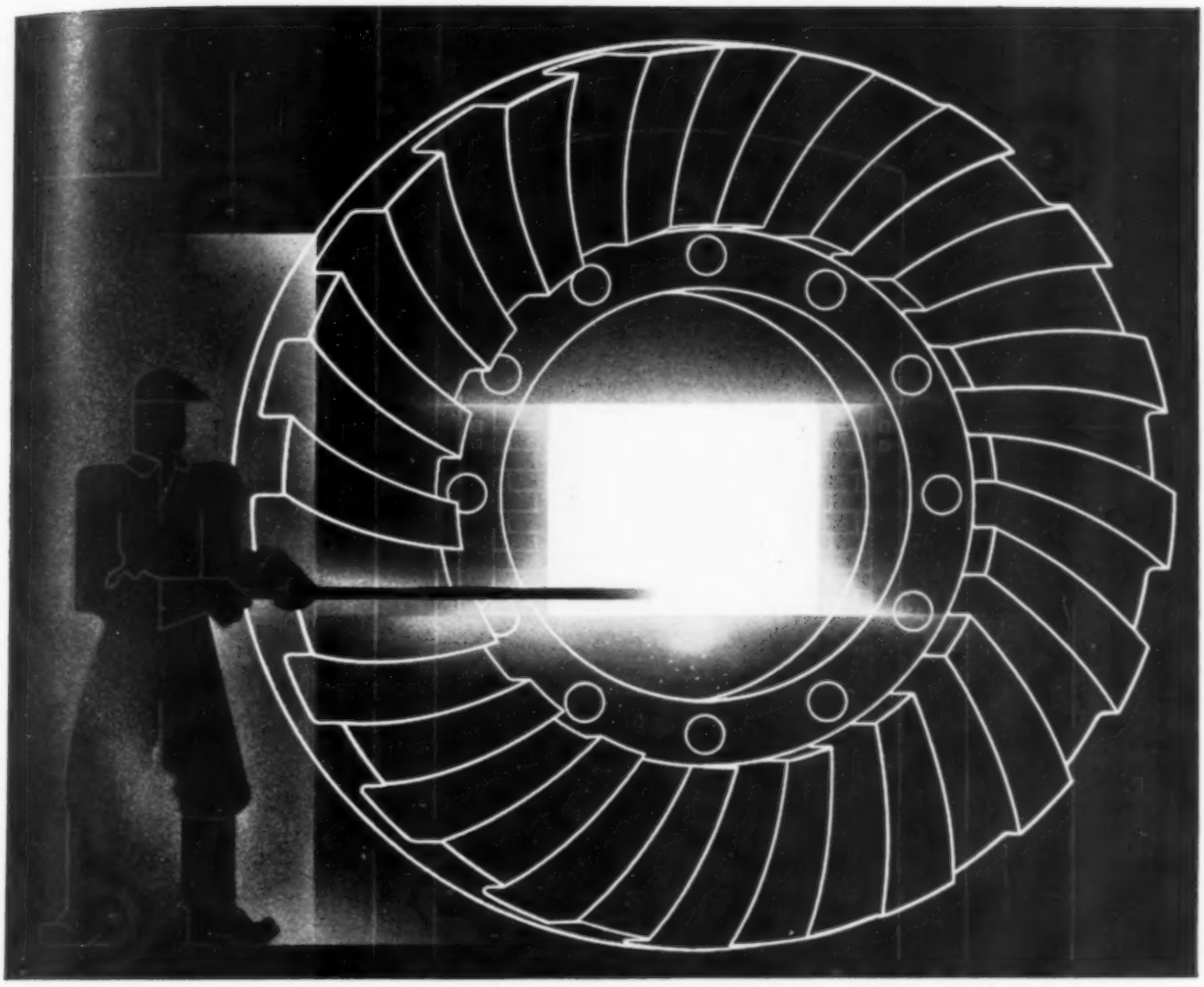

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PERSONALS

J. W. Weitzenkorn has become associated with the Ohio Ferro-Alloys Corp., Canton, Ohio, as director of research.

Joseph T. Somers has been elected president of Wyckoff Drawn Steel Co. succeeding the late Col. A. W. Wyckoff.

Walter H. Clark has been made metallurgist of Cleveland Pneumatic Tool Co. He will also continue in his former position as metallurgist for Cleveland Rock Drill Co.

J. R. Gordon has severed his connection with the Ontario Research Foundation and joined the research department of International Nickel Co. of Canada, Ltd., Copper Cliff, Ont.

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W. B. Thompson, formerly assistant to the general manager of Shawinigan Chemicals, Ltd., Stainless Steel and Alloys Division, has been transferred to St. Catharines, Ont., as manager of the Ontario office.

Walther H. Mathesius, son of Trustee Mathesius, is employed at the U. S. Steel Corp. Research Laboratory, Kearny, N. J.

William E. Crocombe has been elected vice-president of American Brake Shoe & Foundry Co.

J. S. Vanick, a member of the Development and Research Division, International Nickel Co., will visit several South American countries during the next few months, accompanied by **E. F. Feely**, representative of the company in South America. They will offer consultation service on nickel alloys to executives and engineers.

H. S. Card, formerly editor of The Welding Engineer, has been appointed development director of the National Electrical Manufacturers Association's newly established Electric Welding Development Section in Pittsburgh.

Everett Chapman, formerly vice-president of Lukenweld, Inc., has been elected president of the company. **Robert J. Whiting**, formerly superintendent in charge of all manufacturing, has been elected vice-president.

Lester M. Curtiss has been promoted from superintendent of production to assistant general superintendent, Lukens Steel Co.

O. W. Winter is now industrial engineer for Kent Owens Machine Co., Toledo, Ohio.

R. P. Wray has transferred from the Duquesne Works of Carnegie-Illinois Steel Corp. to the United States Steel Corp. Research Laboratory, Kearny, N. J.

A. H. Lewis is now employed by the Dominion Engineering Co., Ltd., Montreal.

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PERSONALS

Wilson Lynes is metallurgist with Henry Disston & Sons, Inc., Philadelphia.

Peyton R. Russell has joined the general metallurgical staff of Republic Steel Corp. in Massillon specializing in pickling and coating practices.

G. Vernon Eads has become associated with the Commercial Division of Carnegie-Illinois Steel Corp., Pittsburgh.

John B. Edwards has accepted a position in the Development Division of the Electro Metallurgical Corp.

F. Karl Hansen is now in the Metallurgical Department of the Carnegie-Illinois Steel Corp., Pittsburgh.

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J. H. Zimmerman has left the Massachusetts Institute of Technology teaching staff to take charge of the Newark Development Laboratory of the Linde Air Products and associated companies.

John F. Robb, metallurgical engineer for Climax Molybdenum Co., has been transferred from the Pittsburgh to the Canton, Ohio, office.

Gordon McMillin has joined the Buckeye Traction Ditcher Co., Findlay, Ohio, as metallurgist in charge of control of metals.

G. M. Van de Water has left the employ of General Metals Corp., Oakland, Calif., to join American Manganese Steel Co. as metallurgist in Los Angeles.

George K. Minert, formerly metallurgist for Illinois Malleable Iron Co., has been made metallurgist in charge of melting furnaces, Gunite Foundries Corp.

F. O. Farey has opened a testing laboratory under the name of Frank O. Farey Laboratories in Montreal.

George J. Foss, Jr. returns to the University of Notre Dame as graduate assistant in metallurgy.

R. K. Wells has transferred from the Newport News Shipbuilding and Dry Dock Co. to the office of the Inspector of Naval Material, Munhall, Pa., for study at Carnegie Tech.

Ernest Stueckler is employed as mechanical engineer with the Wald Manufacturing Co., Maysville, Ky.

Andre Hone is now assistant to the technical director of the Aluminum Co., Ltd., Montreal.

T. J. Dunn has been transferred by the Worthington Pump and Machinery Co. from the Inspection Department, Rock Drill Division, Harrison Works, to the Mining and Construction Division in the Buffalo District as service engineer.

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GRAIN SIZE

(Cont. from page 55) such as temperature, duration and speed of cooling. The particular meaning attributed to the expressions "grain size of steel" and "grain growth in steel" should be remembered in order to avoid confusion.

The term "grain size of steel" was first limited to the austenitic grain, the gamma grain in hot metal, the element of which is the individual crystal of the gamma solid solution existing above the transformation points of the steel. However, there is also the alpha grain, the fracture grain and the pearlite grain in ordinary steel at atmospheric temperature, whose relations with the austenitic grain are complex and not very well known. This before-mentioned austenitic grain could be easily defined if it could be observed and measured while the steel is hot, but since it disappears when the steel is cold, it can only be known indirectly from the fact that, under definite conditions of treatment, there is a hereditary relationship between the structure when cold and the original austenite.

The number N of austenitic grains per unit of surface in any cross section of the metal varies inversely as the average grain size, and the latter may be estimated by the formula $G = 1 \div \sqrt{N^3}$. Ordinarily the classification of grain size is made according to the terms of a geometrical progression of ratio 2.

For a given heat treatment, grain size depends on the steel, particularly the method of manufacture; on the other hand, for a given steel, grain size depends on heat treatment, that is to say, the temperature T_c and duration t_c of heating. In all steels the gamma grain is fine immediately after completion of the $\alpha \rightarrow \gamma$ transformation on heating, and then at the temperature T' where superheating begins, some grains grow at the expense of neighboring ones, and this continues until a temperature T'', at which all the fine grains have disappeared.

For a given length of heating t_c all steels have a temperature or superheat interval $T'' - T'$, sometimes very narrow, below which the grain is fine, above which it is coarse, and within which the grains have variable dimensions and are designated "mixed grains." In other words, the curve $N = f(T_c, t_c)$ possesses two critical values for T' and T'' with t_c constant.

(Continued on page 94)

Airplane photograph of City of Cleveland, with National Metal Exposition ringed in white. Flown and photographed by H. H. Harris.

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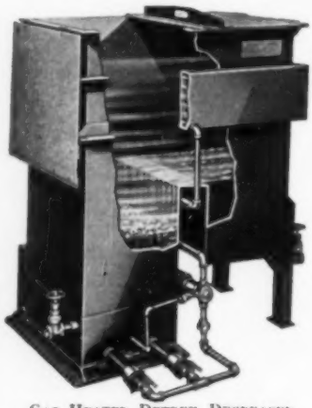

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GRAIN SIZE

(Starts on page 55)

There are actually no steels specifically fine grained, mixed grained or coarse grained, this condition depending on the annealing; all steels may belong successively in the three categories, and classification according to a given test depends on the interval of superheat $T''-T'$ as it is related to the conditions of the test, just as the practical significance of the test depends on the relationship between the conditions of test and the conditions of use.

The test generally used is the McQuaid-Ehn carburizing test, in which the grain is conventionally defined as that in the hyper-eutectoid case after carburizing for 8 hr. at 1700° F. in solid carburizer and cooling in the pot, this taking from 20 to 25 hr.

Although this test is carefully defined as to operating technique and is very convenient for evaluating N, its significance is limited. First, it presupposes that carburization does not change the grain size, which is not always true; second, it neglects the influence of prior treatments, either thermal or mechanical; and third, it gives only a relative indication of the relation of the interval or temperature of superheating to the chosen temperature (1700° F.) and duration of the test. In other words, only one point of the superheating curve $N = f(T_c)$ is obtained for the value t_c, and this hardly seems sufficient to characterize a coarsening tendency.

Thus this test is not really sufficient to define exactly the influence of addition elements, particularly those inhibiting grain growth, such as aluminum, titanium, vanadium and tungsten. It is necessary to study the influence of the actual content of addition elements on the superheating temperatures T' and T''; this information can be given in the form of two curves presenting critical values. Likewise the effect of mechanical treatments must be studied.

Finally, grain growth, or coalescence of austenite, must not be confused with abnormality, or coalescence of cementite. For instance, the addition of aluminum refines the grain and makes the steel abnormal, while the addition of vanadium likewise refines the grain (when added in amounts five to ten times as large to obtain equivalent results) but does not make the steel abnormal.

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PIG IRON

(Continued from page 55) in a region where the chemical industry produces large quantities of calcined pyrites, and where the demand for iron and steel is very heavy.

The low cost of electric power, produced in the Alps nearby in hydro-electric power plants owned by the same company, rendered the use of electric furnaces advisable in every respect. However, as is well known, the results obtained so far with electric furnaces for the reduction of iron ore to pig iron have been satisfactory only in special cases. For instance, the "Elektrometall" furnaces have been successfully used only in Sweden, where power and charcoal are both extremely cheap; serious troubles have arisen when the same furnaces have been used with coke as a reducing element.

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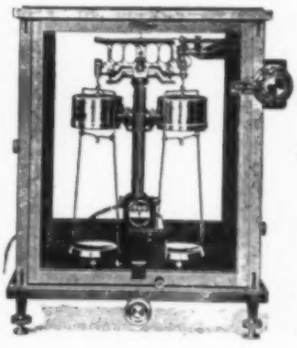

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Required by the Act of Congress of August 24, 1912, and March 3, 1933, of METAL PROGRESS, published monthly at Cleveland, Ohio, for October 1, 1936.

State of Ohio } ss.
County of Cuyahoga }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Ray T. Bayless, who, having been duly sworn according to law, deposes and says that he is the business manager of METAL PROGRESS and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management, etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business manager are: Publisher, American Society for Metals, 7016 Euclid Ave., Cleveland, Ohio; Editor and Managing Editor, Ernest E. Thum, 7016 Euclid Ave., Cleveland, Ohio; Business Manager, Ray T. Bayless, 7016 Euclid Ave., Cleveland Ohio.

2. That the owner is: The American Society for Metals, 7016 Euclid Ave., Cleveland, O., which is an educational institution, the officers being, President, R. S. Archer; Vice President, E. C. Bain; Treasurer, W. P. Woodside; Secretary, W. H. Eisenman; Trustees: B. F. Shepherd, Walter Mathesius, G. B. Waterhouse, R. L. Kenyon, S. C. Spalding. All officers as above, address 7016 Euclid Ave., Cleveland, Ohio.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

RAY T. BAYLESS,
Business Manager.

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Sworn to and subscribed before me this 1st day of October, 1936.

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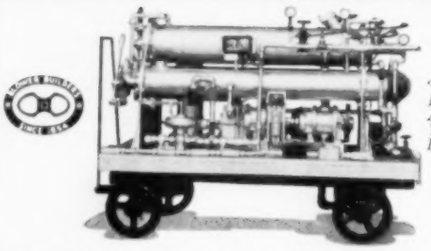

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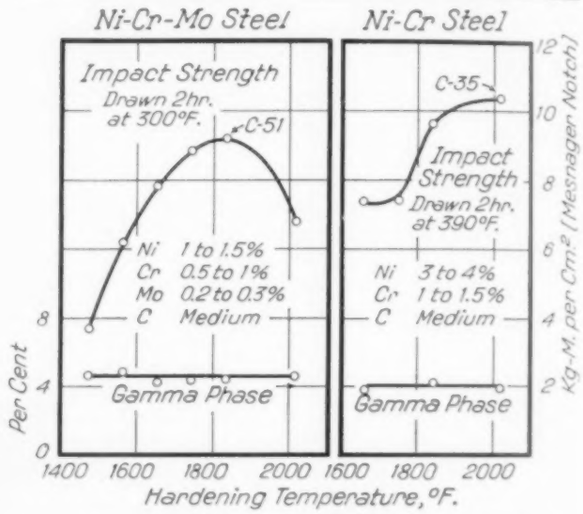
TOUGH STEEL

(Continued from page 54) amount of residual austenite and hardening temperature for two of the steels investigated. In the case of the nickel-chromium-tungsten steel, the optimum heat treatment (quench from 1825° F., temper 5 hr. at 300° F.) gave a hardness of Rockwell



Impact Strength of Two Alloy Steels, Oil Quenched From High Temperature and Drawn at Low Temperature, Thus Retaining Much Austenite. Mesnager test specimen is 10x10x55 mm., notched 2 mm. deep with bottom rounded to 1-mm. radius

C-44 and an impact strength of 9.8. In all cases the amount of residual austenite was determined by comparing the unknown sample with a standard specimen, quenched from 1750° F. and tempered for a long time at 660° F., the magnetic saturation of which was considered as the saturation of the pure alpha phase (that is, a wholly transformed sample).

Therefore, we see that the increase of impact strength with the increase of hardening temperature observed in the case of hypoeutectoid steels is not connected with any change in the amount of residual austenite. It is quite possible that the increase of impact strength is caused by the more uniform solution of carbides or the solution of impurities present along the grain boundaries.

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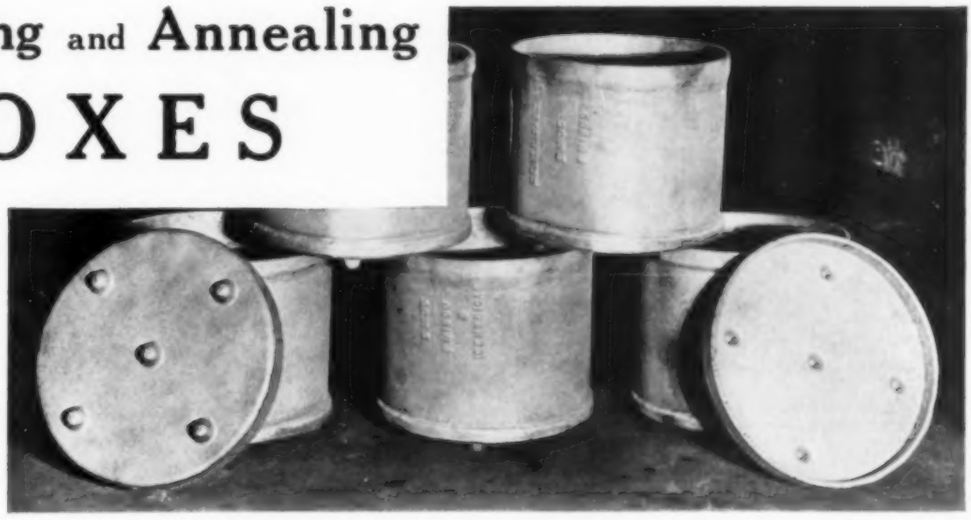

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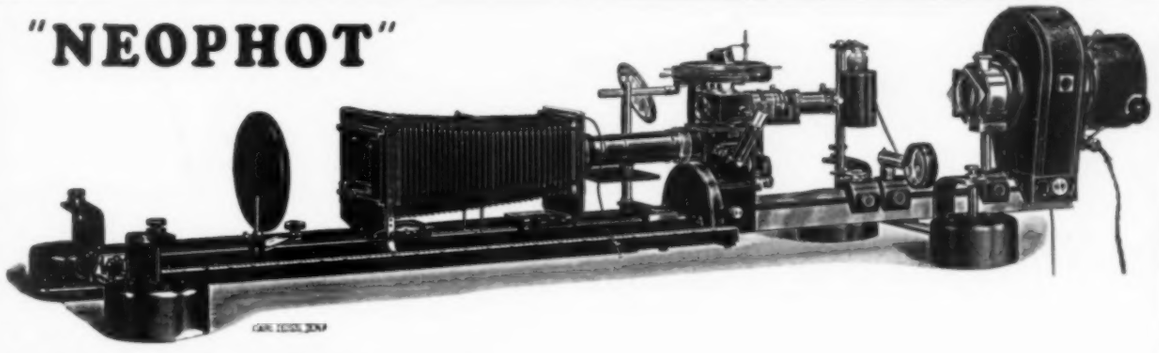

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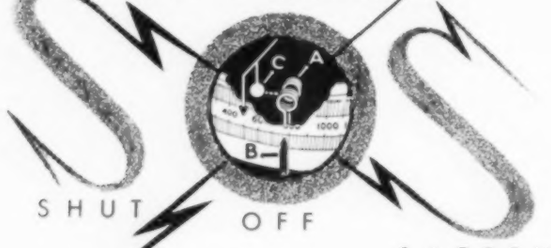

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CAST CRANKS

(Continued from page 52)

were solid. All were made of carbon steels of heat treating grade, specified with 65,000 psi. tensile strength minimum. One hollow bored design and one solid design were heat treated to Brinell 242 to 248, whereas the third hollow shaft was much harder — Brinell 440. It is a noteworthy result of the full-sized torsional tests that differences in design and heat treatment made scarcely any difference, the torsional endurance being 11,400 to 12,100 psi., despite the fact that the ultimate tensile strength may be

Endurance Tests on Crankshafts

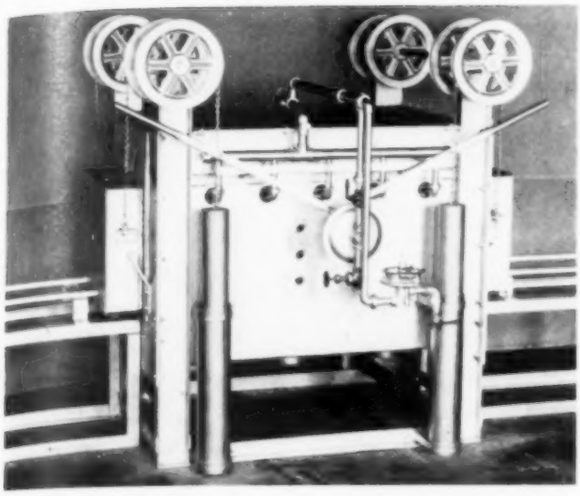
Bearings		Cast Iron		Forged Steel
Diameter	Design	Variety	Endurance Limit, psi.	
Torsion Tests on Model Shafts, Single Throw				
0.551 in.	Solid	Pearlitic	14,200	20,000
0.551	Solid	Malleable	17,000	—
0.551	Solid, Flame Hardened	Malleable	19,500	—
Torsion Tests on Four-Throw Shafts, Full Size				
1.889 in.	Hollow	Pearlitic	7,800	11,500
1.889	Hollow, Flame Hardened	Malleable	8,500	—
1.889	Porsche	Pearlitic	9,000	—
Bending Tests on Four-Throw Shafts, Full Size				
1.889 in.	Hollow	Pearlitic	7,100	11,300
1.889	Hollow, Flame Hardened	Malleable	9,300	—

inferred from the hardness to be 120,000 psi. in two designs and 210,000 psi. in the third. It is an inescapable conclusion that the strength of the structure depends primarily on the design, and only slightly on the material.

It should be noted that the observed fractures in these tests correspond in appearance and location to those occurring in regular operation of the automobile engines using these particular designs, and start either at the oil hole or at the transition from pin to cheeks.

One of the three designs of shafts (the one heat treated to high hardness) was also subjected to an endurance bending test on a Losenhausen pulsation machine in such a way that the bending moment was highest either in the connecting rod pin or in the cheeks adjoining. Under these conditions the endurance in bend-

(Continued on page 102)



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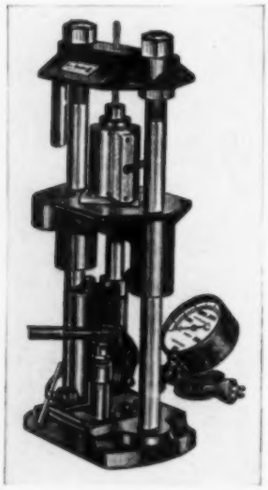

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OPTICAL INSTRUMENTS • METALLURGICAL APPARATUS

CAST CRANKS

(Starts on page 52)

ing was 6400 psi. in the pin, and 11,400 psi. in the cheek. It can be seen that endurance in bending stress in the hardened hollow bored crankshaft is considerably lower than in torsional stress. Thus, it would appear that abrupt transitions are more dangerous in bending than in torsion.

The above values were compared to those ascertained by identical testing procedure on cast crankshafts. (Among others, the following cast materials are used in Germany in competition with high strength steel forgings: Pearlitic cast iron, black heart malleable, and Ford copper-chromium semi-steel. Cast steel has been used, but has not been widely developed because of the danger of cracks during manufacturing.)

The use of cast iron is again gaining ground because of new conceptions of structural strength. The design of a forged steel crankshaft is conditioned by the forging and machining work. In a cast design, on the other hand, it is possible to use other contours with increased economy. As demonstrated above, the determining factor is not the tensile strength but the torsional endurance and the resistance to bending stresses.

The table on page 100 gives an interesting comparison of the strength of crankshafts made of cast iron and of high strength steel. From these and other test results it can be concluded that the endurance of pearlitic cast iron and hardened malleable iron shafts, tested full size, is about 65% of the strength of the steel shafts.

It should be noted that in this table the cast materials were tested in the same form as stipulated for steel. By the adoption of newer designs giving optimum properties for cast iron, great improvements are possible. The Porsch crankshaft, for instance, made of pearlitic cast iron with round disk-shaped cheeks, hollow cored journals and pins, and cored cylindrical cheeks where such are not adjacent to journal bearings, has an endurance in torsional stress of 8500 to 9250 psi. — about 10 to 15% higher than a solid cast shaft of the same design as a steel shaft. It therefore appears that cast iron crankshafts of special design have about 75 to 80% of the strength of steel shafts of equivalent ruling dimensions.

HANS DIERGARTEN